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THE CONSTANT OF ABSOLUTE CONTRACTION AND THE PERIODIC LAW

I. I. Zaslavsky and K. B. Yatsimirsky

The absolute contraction constant is the designation of the ratio of the molecular volume of a compound to the sum of the atomic volumes of its component elements:

$$C = \frac{Vm}{\Sigma V_A}$$

Many researches have ; has been devoted to the study of this magnitude. Earlier Beketov established the existence of a relation between the absolute contraction constant and the heat of formation of a compound [1]. One of us has established a relation between the contraction constant and the acid-base properties of compounds [2], and also their crystalline structure [3].

Recognizing that contraction is one of the characteristics of a substance most amenable to experimental determination, and bearing in mind the close link between the contraction constant and the totality of other physico-chemical properties, we resolved to follow the change in the values of the constant in question in a series of analogous compounds (oxides, sulfides, halides, etc.) with change in the atomic number of the element.

With the aim of obtaining comparative results we always utilized the contraction constants of the densest modifications and plotted the values only of those compounds whose valency exactly corresponds to the number of the group of the periodic system. The contraction constants of oxides (for this group of compounds it proved possible to obtain the fullest data), plotted in the order of magnitude of the atomic numbers of the elements, are shown in the diagram.

In the second and third periods the contraction constant of oxides as a rule increases with increasing atomic number of the element. Deviation from this rule is observed, however, in the case of N_2O_3, due evidently to the structural peculiarities of this compound; furthermore the contractions of P_2O_5 and SO_3 are almost identical.

In the fourth and fifth periods the contraction constant regularly increases from the first to the eighth group; starting from the first subgroup, it decreases to the fourth group and then again rises slowly.

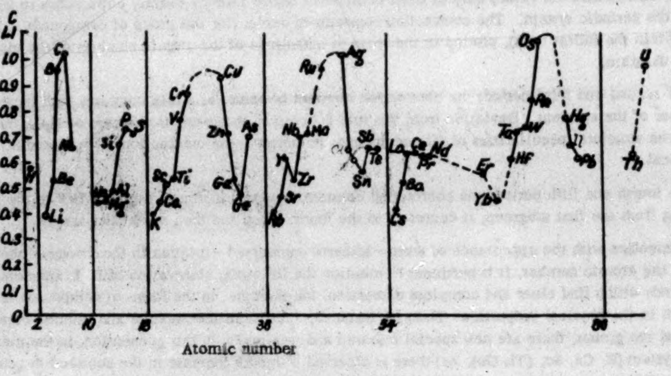
In connection with the appearance of these – hitherto unobserved – minima in the change of the contraction constant with the atomic number, it is pertinent to mention the following observation of D. I. Mendeleev [4]: ". . . the periods which find clear and complete expression, for example, in the forms of compounds, are complicated to some extent in the physical properties. Thus, for instance, apart from the maxima and minima corresponding to the periods and the groups, there are new special maxima and minima". In this connection, in the main groups of the periodic system [K, Ca, Sc, (Ti, Ge), As] there is observed a smooth increase in the contraction constant, i.e., approximately the same regularity is repeated as in the preceding periods.

In the fifth period a decline is observed in the contraction constant in passage from yttrium oxide to zirconium oxide. In the sixth period, however, the contraction constants of the lanthanides regularly decrease with increasing atomic number, evidently due to the well-known phenomenon of "lanthanide contraction". The contraction constant of HfO_2 is lower than that of La_2O_3. For the rest, the change of contraction constant is accompanied by the same regularity as in the two preceding periods. It is difficult to evaluate the change of contraction constant in the seventh period owing to the lack of an adequate amount of experimental material.

TABLE 1

Contraction and Electric Conductivity of Chlorides

LiCl 0.69 166	$BeCl_2$ 1.10 < 0.086	BCl_3 1.17 0	CCl_4 1.08 0	–
NaCl 0.67 133.5	$MgCl_2$ 0.86 28.8	$AlCl_3$ 0.91 $15 \cdot 10^{-6}$	$SiCl_4$ 1.07 0	PCl_5 > 1 0
KCl 0.60 103.5	$CaCl_2$ 0.87 51.9	$ScCl_3$ 0.93 15	$TiCl_4$ 1.13 0	VCl_5 ? 0
RbCl 0.60 78.2	$SrCl_2$ 0.77 55.7	YCl_3 0.98 9.5	$ZrCl_4$ 1.02 ?	$NbCl_5$ 1.04 $2 \cdot 10^{-7}$
CsCl 0.48 66.7	$BaCl_2$ 0.67 64.6	$LaCl_3$ 0.86 29.0	$HfCl_4$? ?	$TaCl_5$ 1.03 $2 \cdot 10^{-7}$
–	$RaCl_2$ – ? ?	$AcCl_3$? ?	$ThCl_4$ 0.94 16	$PaCl_5$? ?



Contraction constants of higher oxides

As a rule the lowest contraction values are observed with typically ionic compounds (oxides of the alkali and alkali earth metals and oxides of lanthanides), whereas the highest values are observed with typical molecular compounds as well as with oxides of the eighth and adjacent groups where the characteristic features of the covalent type of bond are ever more prominently developed.

There is no doubt, therefore, that a definite close relationship exists between the type of chemical bond and the absolute contraction constant. This may be confirmed by a large amount of experimental material.

TABLE 2

Contraction Constants of Oxides and the Periodic Law (for the Densest Modifications)

Li_2O 0.39	BeO 0.53	B_2O_3 0.96	CO_2 1.02	N_2O_5 0.66	– 	–
Na_2O 0.44	MgO 0.45	Al_2O_3 0.49	SiO_2 0.67	P_2O_5 0.73	SO_3 0.72	Cl_2O_7 –
K_2O 0.40	CaO 0.45	Sc_2O_3 0.52	TiO_2 0.54	V_2O_5 0.77	CrO_3 0.87	Mn_2O_7 –
Rb_2O 0.41	SrO 0.46	Y_2O_3 0.61	ZrO_2 0.53	Nb_2O_5 0.70	MoO_3 0.72	Tc_2O_7 –
Cs_2O 0.42	BaO 0.52	La_2O_3 0.64	HfO_2 0.62	Ta_2O_5 0.72	WO_3 0.74	Re_2O_7 0.84
–	RaO –	Ac_2O_3 –	ThO_2 0.63	Pa_2O_5 –	UO_3 0.97	–

The electric conductivity of pure substances in the fused state is regarded as one of the most important criteria of the type of chemical bond in compounds. Biltz and Klemm [5] measured the electric conductivity of fused chlorides and on the basis of the experimental data they drew a line between compounds which conduct current and those which are nonconductors, ie. between those which are typically ionic and those compounds characterized by the presence of a covalent bond. Herein is reproduced the table generally appearing in textbooks of inorganic and physical chemistry and in geochemical literature (Table 1).

The left-hand columns of the table contain the absolute contraction constants and the line divides compounds formed with a low finite volume ($C < 1$) from compounds whose formation from the elements is accompanied by expansion. It was found that, with one exception ($AlCl_3$), the boundary line coincides with the line separating compounds that conduct current when melted from nonconductors. It may be noted that the increase of molecular volume of aluminum chloride when melted is slightly greater than that of other similar compounds. In the case of bromides and iodides the line demarcating compounds with $C<1$ from compounds with $C > 1$ passes lower and more to the left than in the case of chlorides, while with the corresponding fluorides it passes a little higher and a little more to the right.

On constructing a similar table for oxides (Table 2) it is found that the line dividing compounds with $C < 0.65$ from compounds with $C > 0.65$ is also the line which Fersman [6] considers to be the boundary between elements giving typical ions and those with molecular lattices.

The foregoing discussion also leads to the conclusion that to a certain extent the contraction constant may characterize the degree of polarization in chemical compounds. We know that the polarization of compounds with one and the same cation increases with increasing dimensions of the anion.

On this basis we can expect an increase of the contraction constants in the order of fluorides, chlorides, bromides and iodides, and also of oxides, sulfides, selenides and tellurides (in both cases the comparison is between compounds containing one and the same cation). Such a rise in contraction constants is actually observed in all known cases. It is also known that in compounds containing cations of the copper and zinc subgroup the polarization is stronger than in compounds of the alkali and alkali earth metals. This regularity is also confirmed on comparing the contraction constants of the corresponding compounds: The contraction constants of the subgroups are always higher than those of the analogous main groups. And the biggest difference is observed in the first group of the periodic system, the next biggest in the second group, followed by the difference in the third group. Finally in the fourth group such differences between the contraction constants of the main and subgroups have disappeared completely.

Pauling [7] showed that the heat of formation of chemical compounds in the standard state is higher the more pronounced is the ionic character of the compound. From this standpoint Beketov's [1] observation of the relation between contraction constant and heat of formation becomes understandable. The more pronounced is the ionic character of the bond in the compound in question, the smaller is the contraction constant, and the higher is the heat of formation of the compound.

The relation which we have established between the absolute contraction constant and the periodic law permits some additional conclusions about the geochemical characterization of the elements. It appears that elements forming oxides with higher contraction constants ($C > 0.95$) are the most frequently encountered in nature in the native state. Elements forming oxides with lower constants (0.65-0.95) are found in nature either in the form of complex ions (W, Nb, Ta, etc.) or of sulfides (Hg, Zn, Cd, As, etc.). Elements whose oxides are characterized by maximum contraction during formation from simple starting materials ($C < 0.95$) are encountered in nature in the form of simple cations (K, Na, Ca, Sr, Ba, etc.).

SUMMARY

1. It is established that the absolute contraction constant of typical compounds of the elements (oxides, halides, sulfides, etc.) is a periodic function of the atomic numbers of these elements.

2. It is shown that to a certain extent the magnitude of the contraction constant can serve as a criterion of the character of the chemical bond in a given group of compounds. A correlation is established between contraction constant and electric conductivity of pure compounds, their polarizations and heats of formation.

3. A relation is demonstrated between the geochemical characteristic of elements and the contraction constant of their typical compounds.

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POLAROGRAPHIC CHARACTERISTICS OF CADMIUM, LEAD AND THALLIUM IN AQUEOUS-ALCOHOLIC SOLUTIONS OF VARIOUS INDIFFERENT ELECTROLYTES

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Studies of the influence of a nonaqueous solvent on the polarographic characteristics of metallic ions can play an important part in the further development of both polarography and the theory of solutions. Nevertheless this problem has received little attention in the literature.

Researches in this direction with mixed solvents (including water-alcohol [1,2]) revealed firstly the continued validity of the expression $i_d = kC$, and secondly a drop in the value of the diffusion current with increasing content of the nonaqueous solvent but the constancy of the half-wave potential [2] has remained unexplained, as far as we can ascertain.

A series of investigations has been devoted to the polarographic behavior of various substances in absolute nonaqueous solvents. Many ions of heavy metals, for instance, have been studied in acetic acid [3]; alkali metals, thallium, ammonium, copper, and oxygen in liquid ammonia [4]; tin in methyl alcohol [5]; and cobalt, silver, arsenic and oxygen in pyridine (using a platinum microelectrode) [6]. The validity of the expression $i_d = kC$ could be confirmed for Pb, Cd, Zn, Co, Cr and Ni in acetic acid [3] and for Co and As in pyridine [6]. Half-wave potentials were also obtained in acetic acid and were found to be more negative than those in water. In many cases also, the reversibility was demonstrated of the reduction process, for instance for ions of the alkali metals, thallium, ammonium and copper ($Cu^{\cdot\cdot} \rightarrow Cu^{\cdot}$) in liquid ammonia [4] and for tin in methyl alcohol [5].

Finally reference may be made to the successful use by I. A. Korshunov [7] of mixed solvents for the purpose of amperometric titration.

The aim of the present investigation is the study of the dependence of the magnitude of the half-wave potential on the diffusion current of cadmium, lead and thallium and on the content of ethyl alcohol in aqueous-alcoholic solutions of various indifferent electrolytes.

EXPERIMENTAL

The solutions were prepared from analytically pure $Cd(NO_3)_2$ ($1\cdot 10^{-3}$ molar), $Pb(NO_3)_2$ ($2\cdot 10^{-3}$ molar) and $TlNO_3$ ($1\cdot 10^{-3}$ molar). Use was made as indifferent electrolytes of KNO_3 (0.1 molar), NH_4NO_3 (0.1 and 0.9 molar), NH_4Cl (0.9 molar) and KI (0.9 molar). Maxima were suppressed by addition to the solution of 0.01% gelatin. The aqueous-alcoholic solvent was prepared from absolute ethanol. Solvents containing 20, 45 and 65% (by volume) of alcohol were investigated. Comparison polarograms in water were plotted. Polarographic determination was performed with the help of a visual polarograph (Gorki University model) supplemented by a sliding-contact potentiometric set-up. A saturated calomel electrode was used as the nonpolarizing anode. Measurements were made at a temperature of 25 ± 0.2°C. Volatilization of solvent on passage of a hydrogen stream proved to be so slight that it was not necessary to saturate the hydrogen beforehand with the vapor of the solvent.

The characteristics of the capillary used in the investigation are shown in Table 1. It is seen that increasing alcoholic content is accompanied in line with the measurements of Zanko and Manusova [2], with a slight reduction in the dropping period (τ). The weight of mercury discharged in unit time (m) remains independent of the nature of the solvent in agreement with the observations of Kolthof and Lingane [8].

The resistance of the polarographic electrolyzer was determined from the difference of the half-wave potentials corresponding to the difference (1:10) of concentrations of the reduced ion [9]. With increasing

TABLE 1

C_2H_5OH (%)	(0.1-0.9 m NH_4NO_3(KNO_3)) $m_{comp.}$ (mg/sec^{-1})	$\tau_{comp.}$ (sec.)	$m^{2/3}\ \tau^{1/6}$ (mg$^{2/3}$/sec$^{-1/2}$)	0.9 m KI m_{comp} (mg/sec^{-1})	$\tau_{comp.}$ (sec.)	$m^{2/3}\ \tau^{1/6}$ (mg$^{2/3}$/sec$^{-1/2}$)	0.9 m NH_4Cl $m_{comp.}$ (mg/sec^{-1})	$\tau_{comp.}$ (sec.)	$m^{2/3}\ \tau^{1/6}$ (mg$^{2/3}$/sec$^{-1/2}$)
0	1.338	4.00	1.53	1.338	3.69	1.51	1.338	3.92	1.52
20	1.338	3.85	1.52	1.338	3.70	1.51	1.338	3.80	1.52
45	1.338	3.75	1.51	1.338	3.58	1.50	1.338	3.71	1.51
65	1.338	3.75	1.51	1.338	3.66	1.50	1.338	3.63	1.50

alcohol content the resistance of the solution increased considerably. Thus, for example, when the aqueous solution of 0.1 M NH_4NO_3 exhibited a resistance of 1000 ohms, the corresponding aqueous-alcoholic solution with 65% alcohol content had a resistance of approximately 3500 ohms.

The accuracy of the potential of the calomel electrode was checked against the half-wave potential of thallium in 1 N KNO_3 [8].

In addition to the plotting of the respective polarograms, the obtained results were represented graphically in a plot of π against $\log\frac{i}{i_d-i}$, which permitted the determination of the reversibility of the reduction process and also the precise determination of the half-wave potential. An example of diagrams of this type is Figure 1, which represents the results of polarographic measurements on lead and thallium in 0.1 M KNO_3 and of cadmium in 0.9 M KI. The half-wave potentials and angular coefficients of the straight-line plots obtained from Figure 1 and other similar graphs are summarized in Table 2. Also the half-wave potentials are plotted as functions of the alcohol content in Figure 2.

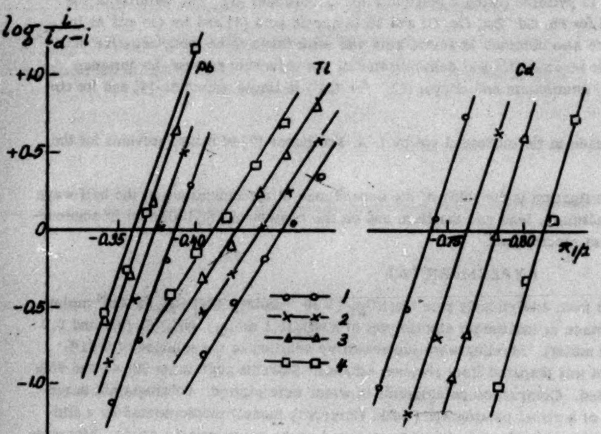

Figure 1. Check of the equation of the polarographic wave of lead and thallium in aqueous-alcoholic solutions of 0.1 M KNO_3, and of cadmium in aqueous-alcoholic solutions of 0.9 M KI.
1 - 0% C_2H_5OH; 2 - 20% C_2H_5OH; 3 - 45% C_2H_5OH; 4 - 65% C_2H_5OH.

The values of the diffusion currents (i_d) and of the diffusion current constants $I_D = \frac{i_d}{m^{2/3}\tau^{1/6}\,C}$ are presented in Table 3 and Figure 3. The values of I_D of solutions $2\cdot10^{-3}$ M $Pb(NO_3)_2$ and of $1\cdot10^{-3}$ M $TlNO_3$ in 0.9 M NH_4Cl at an alcohol content ≥ 45% in the case of lead and ≥20% in the case of thallium were not calculated since these solutions proved to be saturated in relation to chlorides of lead and thallium. The solubility of $PbCl_2$ and of TlCl under the stated conditions was not determined.

Evaluation of Results

We consider in the first place the question of the possible influence of the diffusion potentials on the accuracy of the half-wave potentials measured by us. This point is dealt with by A.I. Brodsky [10] who carried out a detailed investigation of various galvanic chains using aqueous-alcoholic solvents. This author's data justify the assumption that the diffusion potentials had only a very slight effect upon our results. The effect is of the same order (approx. 1 mV) as the accuracy of measurement of the half-wave potentials, so that it may be neglected.

TABLE 2

Half-Wave Potentials of Cd, Pb and Tl in Aqueous-Alcoholic Solutions of Various Indifferent Electrolytes

C_2H_5OH (%)	Cd								Pb			
	0.1 M NH_4NO_3		0.9 M NH_4NO_3		0.9 M NH_4Cl		0.9 M KI		0.1 M KNO_3		0.9 M NH_4Cl	
	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient
0	-0.583	0.035	-0.590	0.034	-0.641	0.029	-0.740	0.030	-0.387	0.034	-0.433	0.034
20	-0.571	0.034	-0.578	0.034	-0.641	0.030	-0.763	0.030	-0.375	0.034	-0.428	0.034
45	-0.560	0.034	-0.569	0.035	-0.650	0.030	-0.784	0.030	-0.366	0.034	-0.433	0.034
65	-0.549	0.034	-0.555	0.035	-0.675	0.030	-0.815	0.032	-0.361	0.035	-0.449	0.030

TABLE 2 -- (continued)

C_2H_5OH (%)	Tl			
	0.1 M KNO_3		0.9 M NH_4Cl	
	$\pi_{1/2}$ (volt)	angular coefficient	$\pi_{1/2}$ (volt)	angular coefficient
0	-0.455	0.060	-0.483	0.059
20	-0.442	0.064	-0.469	0.059
45	-0.426	0.063	-0.466	0.059
65	-0.412	0.062	-0.461	0.058

TABLE 3

Diffusion Currents i_d and Diffusion Current Constants I_D, Cd, Pb and Tl in Aqueous-Alcoholic Solutions of Various Indifferent Electrolytes

C_2H_5OH (%)	Cd							
	0.1 M NH_4NO_3		0.9 M NH_4NO_3		0.9 M NH_4Cl		0.9 M KI	
	i_d, μA	I_D	i_d, μA	I_D	i_d, μA	I_D	i_d, μA	I_D
0	6.00	3.9	6.24	4.1	6.34	4.2	6.54	4.3
20	4.62	3.0	4.69	3.1	5.28	3.5	5.08	3.4
45	3.83	2.5	4.02	2.7	4.49	3.0	4.46	3.0
65	3.53	2.3	3.70	2.4	4.22	2.8	4.46	3.0

TABLE 3 -- (continued)

C_2H_5OH (%)	Pb				Tl			
	0.1 M KNO_3		0.9 M NH_4Cl		0.1 M KNO_3		0.9 M NH_4Cl	
	i_d, μA	I_D	i_d, μA	I_D	i_d, μA	I_D	i_d, μA	I_D
0	12.8	4.2	14.2	4.7	4.75	3.1	4.54	3.0
20	10.10	3.3	11.08	3.6	3.83	2.5	2.44	–
45	8.45	2.7	3.70	–	3.17	2.1	1.43	–
65	7.78	2.6	1.58	–	2.81	1.9	0.69	–

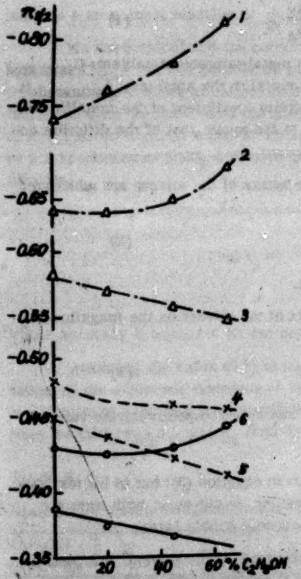

Figure 2. Dependence of the half-wave potential of cadmium, lead and thallium on the alcohol content in aqueous-alcoholic solutions of various indifferent electrolytes. 1 - Cd in 0.9 M KI; 2 - Cd in 0.9 M NH_4Cl; 3 - Cd in 0.1 M NH_4NO_3; 4 - Tl in 0.9 M NH_4Cl; 5 - Tl in 0.1 M KNO_3; 6 - Pb in 0.9 M NH_4Cl; 7 - Pb in 0.1 M KNO_3.

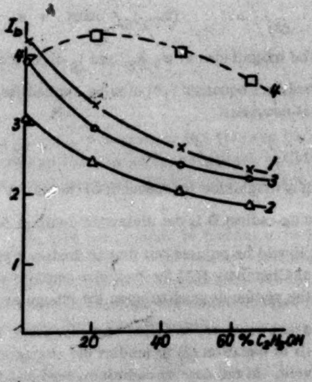

Figure 3. Dependence of the diffusion current constant on the alcohol content in the aqueous-solvent. 1 - Pb in 0.1 M KNO_3; 2 - Tl in 0.1 M KNO_3; 3 - Cd in 0.1 M NH_4NO_3; 4 - ditto with correction for the change of viscosity.

The determination of the angular coefficients of the straight lines representing the dependence of the potential π on the $\log \frac{i}{i_d - i}$ (Table 2) shows that in all the cases under consideration the angular coefficient was close to the theoretical value of $2.3\frac{RT}{nF}$ [8]. It is necessary to emphasize that the correct value of the angular coefficient was only obtained after a correction had been applied to all the points on the polarographic wave which took into account the voltage drop in the electrolyzer. The agreement between the theoretical and experimental angular coefficients permits us to draw the conclusion that regardless of the alcohol content the process of reduction of $Cd^{\cdot\cdot}$, $Pb^{\cdot\cdot}$ and $Tl^{\cdot}$ proceeds reversibly at the dropping mercury electrode.

The half-wave potentials of cadmium, lead and thallium in the investigated indifferent electrolytes (Table 2, Figure 2) changed with changing content of alcohol in opposition to the conclusions of A.M. Zanko and F. A. Manusova [2]. In solutions of $NH_4NO_3(KNO_3)$ the half-wave potentials of cadmium, lead and thallium become more positive with increasing alcohol content; the same is true of the half-wave potentials of thallium in NH_4Cl solutions; on the other hand in NH_4Cl and KI solutions the half-wave potentials of cadmium and lead are shifted in the direction of negative values.

For the purpose of clarifying the cause of this phenomenon we shall first consider indifferent electrolytes in which complex formation does not occur. Among the solutions which we have examined, this condition is met by solutions of $NH_4NO_3(KNO_3)$. As illustrated by the case of cadmium (Table 2) a nearly tenfold change of NH_4NO_3 concentration has very little effect on the magnitude of the half-wave potential. This is observed in all cases regardless of the alcohol content and is only possible in the absence of complex formation.

Considering the above-noted reversibility of the process of reduction of $Cd^{\cdot\cdot}$, $Pb^{\cdot\cdot}$, and $Tl^{\cdot}$, the half-wave potentials of these ions in the absence of complex formation may be determined from the following thermodynamic equation [8]:

$$(\pi_{1/2})_S = \pi_0 + \pi_S + \frac{0.059}{n} \log C_{\text{saturated}}\, f_{\text{saturated}} - \frac{0.059}{n} \log \frac{f_a k_S}{f_S k_a}, \qquad (1)$$

where π_0 is the normal potential of the metal; π_S is the e.m.f. of the system metal-saturated amalgam; $C_{\text{saturated}}$ is the solubility of the metal in mercury; f_a is the activity coefficient of the metal in the amalgam; $f_{\text{saturated}}$ is the same coefficient when the amalgam is saturated with metal; f_S is the activity coefficient of the metallic ions in solution; k_S is the diffusion current constant; k_a is a constant proportional to the square root of the diffusion coefficient of metallic atoms in the amalgam.

Equation (1) may be rewritten thus if all the terms independent of the nature of the solvent are substituted by the term "const":

$$(\pi_{1/2})_S = \text{const.} + \pi_0 - \frac{0.059}{n} \log \frac{k_S}{f_S}. \qquad (2)$$

The magnitudes of π_0, k_S, and f_S depend on the nature of the solvent.

Brodsky's equation [10] may be applied for determination of the effect of the solvent on the magnitude of the normal potential:

$$\pi_0 = A \pm \frac{B}{D}, \qquad (3)$$

where A is a magnitude independent of the nature of the solvent; $B = \frac{en_i}{2a_i}$ (n_i and a_i are respectively the valence and the ionic radius), D is the dielectric constant of the solvent.

It should be pointed out that in Brodsky's paper [10] a plus sign appears in equation (3); but in his textbook on Physical Chemistry [11] the equation contains a minus sign. Generally speaking, in our view, both signs are possible, the choice depending upon the charge on the outer surface of the electrical double layer.

Having assumed, to a first approximation, that a_i is independent of the nature of the solvent, it is possible on the basis of equation (3) to predict the character of the change of the normal potential with changing nature of the solvent. In the case of cadmium, lead and thallium, when the charge on the outer surface of the electric double layer is positive (with an ionic activity equal to 1), the normal potential of these metals must change in the positive direction with increasing alcohol content of the aqueous-alcoholic solvent since the dielectric constant of the solvent will fall at the same time. According to Brodsky [10] in similar conditions the normal potential of the mercury electrode is shifted in the direction of negative values, which is also in conformity with equation (3) if we take into account the negative charge of the outer surface of the electric double layer and, consequently, the negative sign in equation (3).

Let us now return to consideration of equation (2). It follows from this equation that the character of the change of the half-wave potentials of the simple ions $Cd^{\cdot\cdot}$, $Pb^{\cdot\cdot}$ and $Tl^{\cdot}$ with changing content of alcohol in aqueous-alcoholic solvents must be governed by the character of the change of three magnitudes: the normal potential (π_0), the diffusion current constant (k_S) and the activity coefficient of the ion undergoing reduction (f_S). As already noted, the first of these magnitudes (the normal potential of cadmium lead and thallium) will be shifted in the positive direction with increasing alcohol content, while the diffusion current constant (k_S) will decrease (Table 3); the ionic activity coefficient (f_S) will also decrease at the same time as the dielectric constant of the solution.

We have seen (Figure 2) that the half-wave potentials of $Cd^{\cdot\cdot}$, $Pb^{\cdot\cdot}$ and $Tl^{\cdot}$ in aqueous alcoholic solutions of $NH_4NO_3(KNO_3)$ change in the direction of positive values with increasing alcohol content. Even, therefore, with a possible increase in the value of $\frac{k_S}{f_S}$, the effect of increasing alcohol content on the half-wave potential is smaller than the effect of the shift of the normal potential of the metal in the positive direction.

The validity of the above equation (3) of Brodsky has been experimentally confirmed both by the author and by other workers [11]. It is easy to show that our polarographic results for cadmium, lead and thallium in aqueous-alcoholic solutions of $NH_4NO_3(KNO_3)$ can also be utilized for quantitative checking of Brodsky's equation. In fact, on substituting in equation (2) the value of the normal potential in equation (3) we get:

$$(\pi_{1/2})_S + \frac{0.059}{n} \log \frac{k_S}{f_S} = (\pi_{1/2})_{S\,\mathrm{corr.}} = \mathrm{const.} + \frac{B}{D}. \qquad (4)$$

If we assume, as noted above, that a_i in equation (3) is independent of the nature of the solvent, then it follows from equation (3) that if Brodsky's equation is valid the corrected half-wave value $(\pi_{1/2})_{S\,\mathrm{corr.}}$ must be a rectilinear function of $\frac{1}{D}$.

We have calculated the corrected values of the half-wave potentials of cadmium, lead and thallium in 0.1 M KNO_3. For this purpose we calculated the corresponding activity coefficients (f_S) in aqueous-alcoholic solution of 0.1 M KNO_3 at various contents of alcohol. The problem was solved more accurately in the case of thallium, since we know from the literature data [12] that the activity coefficient of Tl in solution with excess of KNO_3 is substantially equal to the activity coefficient of KNO_3. Now we have found the activity coefficients of 0.1 M solution of KNO_3 with various dielectric constants of the solvent from the well-known Debye-Huckel formula:

$$\log f_S = -\frac{250 \cdot n^2 \cdot D^{-\frac{3}{2}} \sqrt{I}}{1 + 2.06 \cdot b_1 D^{-\frac{1}{2}} \sqrt{I}} \qquad (5)$$

whose accuracy is adequate for our purpose.

Assuming the value of b_1 in equation (5) equal to 0.43 A (for KNO_3, according to Dol [13] and the values of the dielectric constants of Table 4 (after Brodsky [10]) then on the basis of the calculated activity coefficients (f_S) we find from equation (4) (left-hand side) the corrected half-wave potentials of thallium. Here we take $(\pi_{1/2})_S$ and k_S from Tables 2 and 3 respectively.

TABLE 4

Dielectric Constants of Aqueous-Alcoholic Solutions

C_2H_5OH (Vol.- %)	0	20	45	65
D	81.7	70.5	56.6	44.9

We have been unable to find any experimental data in the literature for the activity coefficients of cadmium and lead in KNO_3 solution. We therefore only cafried out a rough evaluation of these activity coefficients from the expression:

$$\frac{\log f_{Tl^{\cdot}}}{\log f_{Cd^{\cdot\cdot},\, Pb^{\cdot\cdot}}} = \frac{n^2_{Tl^{\cdot}}}{n^2_{Cd^{\cdot\cdot},\, Pb^{\cdot\cdot}}} = \frac{1}{4},$$

applying the activity coefficients of thallium found from equation (5). Subsequent calculations of the corrected half-wave potentials of cadmium and lead were made as for thallium.

Results of the check of equation (4) are represented in Figure 4 (curve 2). A comparison plot of $(\pi_{1/2})_S$ against $\frac{1}{D}$ is also shown (curve 1).

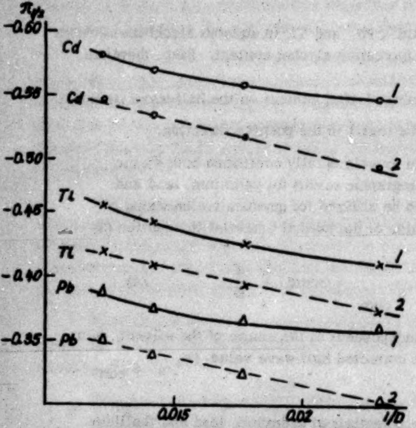

Figure 4. Dependence of the half-wave potential on the dielectric constant of the solvent. Solvent: 0.1 M $KNO_3(NH_4NO_3)$. Curve 1) $\pi_{1/2}$ versus 1/D; Curve 2) $\left(\pi_{1/2} + \frac{0.059}{n} \log \frac{k_S}{f_S}\right)$ versus 1/D.

We see from Figure 4 that the relation between $(\pi_{1/2})_{S\,corr.}$ and 1/D for cadmium, lead and thallium is substantially rectilinear; the small concavity (also found on similar curves in Brodsky's paper) is readily explained by our assumption of the independence of the ionic radius on the nature of the solvent. Brodsky [10] also drew attention to this.

From the foregoing considerations we reach the conclusion that the results of polarography of cadmium, lead and thallium in 0.1 M KNO_3 (NH_4NO_3) confirm the validity of Brodsky's theoretical equation which formulates the dependence of the normal potential of a metal on the nature of the solvent.

The numerical values of B in equation (4) are the corresponding angular coefficients of the straight lines in Figure 4. We can therefore calculate the ionic radii of $Cd^{\cdot\cdot}$, $Pb^{\cdot\cdot}$ and $Tl^{\cdot}$, and these are found to be: $a_{Cd^{\cdot\cdot}} = 3.1$ A, $a_{Pb^{\cdot\cdot}} = 3.4$ A and $a_{Tl^{\cdot}} = 1.9$ A.

We shall now consider the values found for the half-wave potentials of cadmium, lead and thallium in aqueous-alcoholic solutions of NH_4Cl and of cadmium in KI. We know that complex formation occurs even in aqueous solutions of NH_4Cl and KI.

The half-wave potential during reversible reduction of complex ions may be expressed by the following equation [8]:

$$(\pi_{1/2})_C = (\pi_{1/2})_S + \frac{0.059}{n} \log \frac{f_C k_S}{f_S k_C} + \frac{0.059}{n} \log K_C - p\,\frac{0.059}{n} \log C_x f_x, \quad (6)$$

where K_C is the dissociation constant of the complex ion; p is the coordination number; C_x and f_x are the concentration and the activity coefficient of the complex-former; k_C and f_C are the diffusion current constant of the complex ion and its activity coefficient.

Substituting in this equation the value $(\pi_{1/2})_S$ in equation (2) and putting $\frac{f_C k_S}{f_S k_C} \cong 1$, we get:

$$(\pi_{1/2})_C = \text{const.} + \pi_0 - \frac{0.059}{n} \log \frac{k_S}{f_S} + \frac{0.059}{n} \log K_C - p \cdot \frac{0.059}{n} \log C_x f_x. \quad (7)$$

With the exception of the constant C_x, and possibly, p, all the terms in equation (7) depend on the nature of the solvent.

The dissociation constant of the complex ion (K_C) must all with transition from aqueous to aqueous-alcoholic solutions with a lower dielectric constant. This leads, as seen from equation (7), to a shift of the half-wave potential in the direction of negative values. A shift in the same direction also occurs due to possible rise in the value of k_S/f_S with increasing alcohol content; a reverse effect on the magnitude of the half-wave potential is exercised by the change of normal potential (π_0) and of the activity coefficient of the complex-former (f_x).

It follows from our experimental data (Figure 2) that in the case of cadmium and lead in 0.9 M NH_4Cl at high alcohol concentrations and in the case of cadmium in 0.9 M KI at any alcohol concentration, the half-wave potential is shifted in the negative direction with increasing concentration of alcohol. This points to a predominant influence of the factor of reduction of the value of the dissociation constant of the complex ion with increasing alcohol content (7); in this connection a steeper course of curve (Figure 2) is obtained with cadmium (especially in 0.9 M KI), i.e. in this case addition of alcohol causes a sharper fall in the dissociation constant of the complex ion.

Low concentrations of alcohol in solutions of cadmium and lead in 0.9 M NH_4Cl bring about (Figure 2) a small change of half-wave potential with changing alcohol content; this is due to the approximately equal but opposite effect of other factors on the half-wave potential. Figure 2 shows that the half-wave potential of thallium in 0.9 M NH_4Cl is shifted to the negative side with increasing alcohol concentration; the course of the curve is here steeper than in corresponding KNO_3 solutions, evidently as a result, likewise, of complex-formation which is characterized by a slight fall in dissociation constant with increasing alcohol content.

In the present case we cannot draw any quantitative conclusions owing to the lack of experimental material for complex ions in an aqueous-alcoholic solvent.*

We shall now analyze the effect of an aqueous-alcoholic solvent on the magnitude of the diffusion current.

Table 3 and Figure 3 show that the magnitudes of the diffusion currents of cadmium, lead and thallium decrease with increasing alcoholic content. These results are in agreement with those of other authors [1,2].

We attempted to establish to what degree the fall in value of the diffusion current is associated with the fall in ionic diffusion coefficient with increasing viscosity of the solution when alcohol is added. Calculation of the change of diffusion current constant with change of viscosity was carried out with the help of the equations of Stokes-Einstein and Ilkovič [9]. The final expression for obtaining the corrected value of the diffusion current constant ($I_{D_{corr.}}$) had the form:

$$I_{D_{corr.}} = I_D \sqrt{\frac{\eta}{\eta_{H_2O}}}. \tag{8}$$

where I_D is the observed diffusion current constant in the mixed solvent; η is the viscosity coefficient of the mixed solvent; η_{H_2O} is the viscosity coefficient of water.

Making use of the corresponding I_D values in Table 3 and Landolt's viscosity coefficients [14], we obtained the corrected diffusion current constants from equation (8). Results of these calculations for cadmium are plotted in Figure 3 (curve 1). The lead and thallium curves have a similar shape, i.e. they differ from the expected straight line parallel to the abscissas. Nevertheless we see from the cadmium data (Figure 3, curve 1) that the fall in diffusion current constant with increasing alcohol content of the solution proceeds mainly at the expense of a drop in the viscosity coefficient. When analyzing these results we must not forget the slight inaccuracy involved in applying the Stokes-Einstein equation to the case of ionic diffusion.

In conclusion we may note that the very low solubility of lead and thallium salts in aqueous-alcoholic solutions of NH_4Cl, particularly with alcohol contents $\geqslant$ 50% (Table 3) and the considerably higher solubility of cadmium salts in similar solutions create the possibility of polarographic determination in the medium in question of small concentrations of cadmium in presence of a large excess of lead and thallium.

SUMMARY

1. The polarographic characteristics of cadmium, lead and thallium in aqueous-alcoholic solutions of KNO_3, NH_4NO_3, NH_4Cl and KI have been investigated.

2. In all cases, regardless of the alcohol content, reversibility of the process of reduction of cadmium, lead and thallium at the dropping mercury electrode was observed.

3. It is shown that the magnitudes of the half-wave potentials of cadmium, lead and thallium in all the investigated indifferent electrolytes changed with changing content of alcohol, in opposition to the conclusions

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* See our next communication.

of A. M. Zanko and F. A. Manusova [2].

4. In the absence of complex formation (KNO_3, NH_4NO_3) the half-wave potentials of cadmium, lead and thallium changed in the direction of negative values with increasing alcohol content; when complexes were formed, e.g. with cadmium in NH_4Cl and particularly KI, the increase of alcohol concentration may cause a considerable shift of the half-wave potential in the negative direction. The character of the observed change in the half-wave potentials was analyzed with reference to the effect of change of magnitude of the normal potential, the dissociation constant of the complex ion and other factors.

5. On the basis of the polarographic data for cadmium, lead and thallium in aqueous-alcoholic solutions of 0.1 M KNO_3 (NH_4NO_3) it was possible to confirm the validity of Brodsky's equation [10] for these metals. This equation expresses the relation between the normal potential and the dielectric constant of the solvent.

6. A fall is observed in the diffusion current constants of cadmium, lead and thallium with increasing content of alcohol in the solution. This is bound up – as shown by calculations using the Stokes-Einstein and Ilkovič equations – mainly with a fall in the viscosity coefficient of the solvent.

7. The suitability is demonstrated of an aqueous-alcoholic solution of NH_4Cl as a medium for polarographic determination of small concentrations of cadmium in presence of excess of lead and thallium.

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THERMOCHEMISTRY OF NICKEL AMMINE COMPLEXES IN AQUEOUS SOLUTION

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The study of nickel ammine complexes in aqueous solution is of interest both for inorganic and analytical chemistry.

Nickel ammine complexes have been known for a long time [1] and have been studied by many workers, but the process of their formation in solution has received little attention. In particular, data are lacking on the thermochemistry of nickel ammine solutions. Only one determination has been reported [2] for the heat of formation of a solution of $[Ni(NH_3)_6]Cl_2$ [2].

The equilibria in solutions in concentrated ammonia have likewise not been adequately investigated. Fairly accurate data exist for complexes of the type of $[Ni(NH_3)_n]^{2+}$ ($n = 1,2,3,4$) but for complexes with a larger number of addenda ($n > 4$) the data are unreliable [3,4].

The purpose of the present investigation is the study of the thermochemistry and, to some extent, the thermodynamics of nickel ammine solutions.

EXPERIMENTAL

We made use of the previously described apparatus and procedure [5] for the determination of the heats of mixing.

The heat of mixing of $NiCl_2$ solutions with ammonia solutions of different concentrations was determined.

A weighed amount of $NiCl_2$ solution was placed in a glass ampoule onto the side of which was blown a small glass bulb. The vessel was then placed in a calorimeter. Experiments were made with solutions containing about 0.25 g $NiCl_2$ per g of solution; the latter was prepared by dissolving pure $NiCl_2$ in water. The calorimeter was charged with ammonia solutions of various concentrations from 0.5 M to 7.5 M. After a uniform temperature had been established, the ampoule was crushed against the side wall of the calorimeter in the upper part of the space filled with the calorimetric liquid. All measurements were made at the temperature of the outer casing ($25.00 \pm 0.05°$) using a Bechmann thermometer whose entire scale covered one degree, so that the accuracy of reading reached $\pm 0.0002°$. The radiation correction was made graphically.

The weight of the calorimetric liquid was determined with an accuracy of $\pm$ 0.5 g. The error of determination of the aqueous components was about $\pm$ 0.5 g.

The heats of mixing found are listed in Table 1.

The data of Table 1 show that the heat of mixing changes with the ammonia concentration and approaches a constant value with increasing NH_3 concentration. As a check on the obtained heats of mixing we performed an experiment on the determination of the heats of solution of the solid salt $[Ni(NH_3)_6]Cl_2$ in NH_3 solutions with concentrations of 0.5 M to 1 M. In the determination of the heat of solution of the solid salt $[Ni(NH_3)_6]Cl_2$ we made use of the apparatus and method used above. About 1-1.5 g of the solid salt (nickel hexammine chloride) was taken. Heat of solution values are given in Table 2.

On the basis of the experimental data for the heats of mixing we have calculated the equilibrium constant of the reaction:

$$[Ni(NH_3)_4]^{2+}_{aq.} + 2NH_3\ aq. \rightleftharpoons [Ni(NH_3)_6]^{2+}_{aq.} \qquad (1)$$

on the assumption that the formation of the $[Ni(NH_3)_6]^{2+}$ ion proceeds according to the scheme shown.

We confirmed the obtained value of the constant by determinations by the solubility method.

Up to now the equilibrium constant has been determined by the solubility method by measuring the solubility of the simple salt in solutions of the addendum. We determined the equilibrium constant from the solubility of the complex salt $[Ni(NH_3)_6]I_2$ in ammonia solutions of various concentrations. The flask containing the solid salt $[Ni(NH_3)_6]I_2$ in ammonia solution was shaken for several days at a temperature of $25.00 \pm 0.05°$. After equilibrium had been reached the solutions were analyzed for the content of iodine ion.

TABLE 1

Heat of Mixing of Solutions of $NiCl_2$ with Ammonia Solutions of Various Concentrations

No. of Expt.	Concentration: NH_3 (in moles per liter)	Concentration: $NiCl_2$ solution ($NiCl_2$ in 1 g solution)	Temp. (°C) change with radiation correction	Radiation Correction (°C)	Weight of $NiCl_2$ in g	Heat capacity of the calorimeter (in cal.)	Heat of mixing (in kcal)
1	0.47	0.2510	0.5169	0.0073	2.1020	557.8	17.78
2	0.65	0.1878	0.3903	0.0067	1.5070	559.0	18.76
3	0.95	0.2510	0.6521	0.0041	2.3960	556.8	19.65
4	1.17	0.1105	0.1697	0.0067	0.6104	556.8	20.06
5	1.28	0.1878	0.3925	0.0053	1.3810	555.0	20.44
6	2.46	0.2439	0.3502	0.0098	1.0940	551.8	22.80
7	3.60	0.2196	0.4355	0.0047	1.2900	546.5	23.94
8	4.65	0.2439	0.4475	0.0134	1.2600	544.0	25.04
9	5.21	0.2463	0.4339	0.0183	1.2060	546.5	25.48
10	6.24	0.2463	0.5190	0.0018	1.4180	537.6	25.50
11	7.50	0.2463	0.4565	0.0057	1.2160	533.8	25.97

TABLE 2

Heat of Solution of $[Ni(NH_3)_6]Cl_2$ in Ammonia Solutions

	Conc. of NH_3 in moles per liter	Weight of $[Ni(NH_3)_6]Cl_2$ (in g)	Change of temp. (in °C) with radiation correction)	Correction for radiation (in °C)	Heat capacity of calorimeter (in cal)	Heat of solution (in Kcal)
1	0.70	1.0626	0.08519	−0.0407	558.0	−10.40
2	0.50	1.3767	0.1267	0.0000	558.8	−11.92

TABLE 3

Solubility of $[Ni(NH_3)_6]I_2$ in Solutions of Ammonia of Various Concentrations

	NH_3 conc. (in moles per liter)	Solubility of $[Ni(NH_3)_6]I_2$ (in moles per liter)	Concentration of $[Ni(NH_3)_6]^{2+}$	Equilibrium constant of reaction (1)
1	0.25	0.02858	0.001683	1.04
2	0.47	0.02086	0.003160	1.82
3	0.70	0.01626	0.005200	0.96
4	0.97	0.01429	0.006730	0.94
5	1.70	0.01248	0.008828	0.84
6	2.58	0.01172	0.01001	0.88
7	3.39	0.01150	0.01040	0.82
8	4.50	0.01117	–	–
9	7.40	0.01111	–	–
10	8.70	0.01111	–	–
11	10.50	0.01111	–	–
12	12.12	0.01113	–	–

The results are shown in Table 3.

Evaluation of Results

We see from the data of Table 1 that the heat of mixing increases with increasing ammonia concentration and approaches a limit. This behavior suggests that more dilute ammonia solutions contain a few complex ions with a different number of combined molecules of ammonia. With increasing ammonia concentration the proportion of complexes with a smaller ammonia content decreases and only one complex ion begins to preponderate in the solution. The limiting value approached by the heat of mixing is 26 kcal and we assumed this to be the heat of formation of the $[Ni(NH_3)_6]^{2+}$ ion from the Ni^{2+} ion and ammonia.

In order to check the above data for heats of mixing, we measured the heats of solution of the complex salt $[Ni(NH_3)_6]Cl_2$. A direct relation exists between the heat of solution of $[Ni(NH_3)_6]Cl_2$ and the heat of mixing of $NiCl_2$ solution with ammonia solution.

We may write the equations of the two processes as follows:

$$NiCl_2\,aq. + 6NH_3\,aq.' = [Ni(NH_3)_6]Cl_2\,aq.', \qquad (II)$$

$$[Ni(NH_3)_6]Cl_2 \text{ solid} + aq.' = [Ni(NH_3)_6]Cl_2 \text{ aq.}', \qquad (III)$$

where aq' is aqueous ammonia solution.

Let L be the heat of solution of solid $[Ni(NH_3)_6]Cl_2$, and Q the thermal effect of reaction (II). From the thermochemical tables of Britske and Kapustinskii [8] we get the heats of formation of the substances participating in reactions (II) and (III), and we can then calculate the heat of formation of $[Ni(NH_3)_6]Cl_2$ aq' in both equations. For the first equation it is 239.1 + L; for the second it is 210.3 + Q. Equating these values we get:

$$239.1 + L = 210.3 + Q,$$

and hence:

$$Q - L = 28.8 \text{ kcal}. \qquad (1)$$

We see from Table 4 that the heat-of-solution data are in agreement with the heat-of-mixing data.

TABLE 4

Relation Between Heat of Mixing and Heat of Solution

	Concentration (moles/liter)	Heat of solution of $[Ni(NH_3)_6]Cl_2$ L	Heat of mixing of $NiCl_2$ with ammonia solutions Q	Difference between	
				Heat of mixing and heat of solution Q−L	Heat of mixing and heat of solution as reported in the literature
1	0.70	−10.40	18.80	29.20	28.80
2	0.50	−11.92	17.80	29.72	–

Several theories have been advanced about the process of formation of the $Ni(NH_3)_6^{2+}$ ion, but the only one which accounts for the change in heat of mixing is that the formation of the ion proceeds according to the scheme:

$$[Ni(NH_3)_4]^{2+}_{aq.} + 2NH_3 \text{ aq} \rightleftharpoons [Ni(NH_3)_6]^{2+}_{aq.}$$

We calculated the equilibrium constant of reaction (I) from the experimental heats of mixing.

Designating the equilibrium concentrations of $[Ni(NH_3)_6]^{2+}$, $[Ni(NH_3)_4^{2+}]$ and NH_3 respectively by a, b, and c, and bearing in mind that

$$\frac{a}{\beta C^2} = K, \qquad (2)$$

we obtain the following expression for the heat of mixing:

$$Q = \frac{Kc^2}{Kc^2 + 1} \cdot 26 + \frac{1}{Kc^2 + 1} \cdot A, \qquad (3)$$

where 26 is the heat of formation of the $[Ni(NH_3)_6]^{2+}$ ion and A is the heat of formation of the $[Ni(NH_3)_4]^{2+}$ ion (equal to 17 cal).

Following a series of rearrangements we obtain the following expression for the equilibrium constant of the above reaction:

$$K = \frac{Q - A}{(26 - Q)c^2}. \qquad (4)$$

The values of the constant calculated with this formula appear in Table 5.

The mean value of this constant is 0.43. Using this value we calculated the heat of mixing. In the majority of cases the difference between the values obtained and the experimental ones was within the limits of possible experimental error. In some cases, however, it attained a very high value; hence we can only regard the value of the constant as an approximate one.

As a check on the obtained values of the equilibrium constant we determined the same constant by the solubility method. The solubility of the complex salt $[Ni(NH_3)_6]I_2$ in ammonia solutions of various concentrations was measured. With increasing ammonia concentration the solubility of this salt ought to have fallen with the decrease in degree of dissociation of the $[Ni(NH_3)_6]^{2+}$ ion. The solubility product of the complex salt $[Ni(NH_3)_6]I_2$ was calculated from the limiting solubility and was equal to $5.5 \cdot 10^{-6}$. With the help of this value we calculated the concentration of the $[Ni(NH_3)_6]^{2+}$ ion for all the investigated points. We considered the difference between the observed solubility and the calculated concentration of the $[Ni(NH_3)_6]^{2+}$ ion to be the concentration of the $[Ni(NH_3)_4]^{2+}$ ion. The following expression was obtained for the equilibrium constant of reaction (I):

$$K = \frac{SP}{4S^2\left(S - \frac{SP}{4S^2}\right)[NH_3]^2}\,, \qquad (5)$$

where SP is the solubility product of $[Ni(NH_3)_6]I_2$, and S is the solubility of $[Ni(NH_3)_6]I_2$.

TABLE 5

Calculation of the Equilibrium Constants of Reaction (I) from the Thermochemical Data

	NH_3 conc. in moles/liter	Heat of mixing (in kcal)	Equilib. const. of (I)	Heat of mixing (in kcal) calculated from the mean value of the constant
1	0.47	17.78	0.43	17.79
2	0.65	18.76	0.57	18.36
3	0.95	19.65	0.46	19.44
4	1.17	20.06	0.38	20.30
5	1.28	20.44	0.37	20.66
6	2.46	22.80	0.30	23.46
7	3.60	23.94	0.27	24.61
8	4.65	25.04	0.39	25.11
9	5.21	25.48	0.59	25.27
10	6.24	25.50	0.43	25.48
	Mean value		0.43	–

The results of calculation of the constant are presented in Table 3.

Comparison of the constants calculated from the heats of mixing with those from solubility data shows that the values are of the same order although not identical. The deviations may be due to the inadequate accuracy of the calorimetric method. However, similar discrepancies occur in the determination of the stability constants by different methods [6].

The literature data for the stability constants of one and the same ion obtained even by the same method differ among themselves. Thus, for PbI_3^-, Korenman [7] gives a value of $0.93 \cdot 10^{-6}$ to $7.4 \cdot 10^{-6}$. Still wider deviations are found when comparing the data of other authors. On the basis of the equilibrium constants obtained by both methods we can conclude that two molecules of ammonia simultaneously join on to the $Ni(NH_3)_4^{2+}$ ion, and not one molecule as Bjerrum suggested [3].

We applied the obtained thermodynamic data to a series of calculations.

The standard heats of formation of the $[Ni(NH_3)_4]^{2+}$ and $[Ni(NH_3)_6]^{2+}$ ions in solution were calculated, the values being $[Ni(NH_3)_4]^{2+}_{aq.}$. For the former $\Delta H^\circ_{298} = -109.6$ kcal; for the latter $\Delta H^\circ_{298} = -157.3$ kcal.

We calculated the change of free energy during formation of the complex ions of $[Ni(NH_3)_4]^{2+}$ and $[Ni(NH_3)_6]^{2+}$ from the equation:

$$-\Delta Z = RT \ln K, \qquad (6)$$

where K is the equilibrium constant of formation of the given ion.

The following values were obtained: For the reaction: $[Ni(NH_3)_4]^{2+}$ and $[Ni(NH_3)_2]^{2+}$

$$Ni^{2+}_{aq.} + 4NH_{3aq.} = [Ni(NH_3)_4]^{2+}_{aq.} \qquad \Delta Z = 10.5 \text{ kcal.}$$

The equilibrium constant of this reaction was taken from Bjerrum's data [3].

For the reaction:

$$[Ni(NH_3)_4]^{2+}_{aq.} + 2NH_{3aq.} \rightleftharpoons [Ni(NH_3)_6]^{2+}_{aq.} \qquad \Delta Z = 0.13 \text{ kcal}$$

The equilibrium constant of the reaction was taken from our thermodynamic data.

From the heat-of-formation and the change-of-free-energy data we evaluated the entropies of the complex ions of $[Ni(NH_3)_4]^{2+}$ and $[Ni(NH_3)_6]^{2+}$ in solution, the following values being obtained;

$$[Ni(NH_3)_4]^{2+}_{aq.} = 54.3$$

$$[Ni(NH_3)_6]^{2+}_{aq.} = 76.78.$$

Utilizing the heat-of-formation data for the solid salt $[Ni(NH_3)_6]I_2$ and the iodine ion [8], and knowing the heat of formation of the $[Ni(NH_3)_6]^{2+}_{aq.}$ ion, we determined the heat of solution of $[Ni(NH_3)_6]I_2$.

From the heat of solution and the solubility of $[Ni(NH_3)_6]I_2$ we calculated the entropy of solution of the solid salt $[Ni(NH_3)_6]I_2$ which was 2.7.

Knowing the entropy of the ions in solution and the entropy of solution, we calculated the entropy of the solid salt $[Ni(NH_3)_6]I_2$. It is approximately 130.1 cal/g.

SUMMARY

1. Determinations were made of the heats of mixing of $NiCl_2$ solutions with ammonia solutions of various concentrations, and calculations were made of the heats of formation of the $[Ni(NH_3)_6]^{2+}$ and $[Ni(NH_3)_4]^{2+}$ ions in aqueous solution.

2. The equilibrium constant of the reaction:

$$[Ni(NH_3)_4]^{2+}_{aq.} + 2NH_{3aq.} \rightleftharpoons [Ni(NH_3)_6]^{2+}_{aq.}$$

was determined from thermodynamic data and from data for the solubility of $[Ni(NH_3)_6]I_2$ in ammonia solutions. It was equal to $\underline{n} \cdot 10^{-1}$ ($\underline{n}$ = 4–9).

3. The hypothesis is proposed that two molecules of ammonia add on simultaneously to the $[Ni(NH_3)_4]^{2+}$ ion.

4. Approximate calculations are made of the entropies of the $[Ni(NH_3)_6]^{2+}$ and $[Ni(NH_3)_4]^{2+}$ ions in solution, and also of the entropy of the solid salt $[Ni(NH_3)_6]I_2$.

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* See Consultants Bureau translation, p. 2219.

** See Consultants Bureau translation, p. 209.

THE SOLUBILITY PRODUCT OF LEAD HYDROXIDE

I. M. Korenman, F. S. Frum and V. G. Chebakova

The solubility product of lead hydroxide, according to several publications [1-3], is $6.8 \cdot 10^{-13}$. This value is calculated from the solubility of $Pb(OH)_2$ on the assumption that in its saturated solution the electrolyte is completely dissociated. According to other sources [4] the solubility product of lead hydroxide is taken to be equal to $2.8 \cdot 10^{-16}$, but here also complete dissociation is assumed. It is impossible, however, to regard this assumption as justified, for it is known that lead hydroxide is a weak electrolyte. Its dissociation constants [5] are fairly low — $K_1 = 9.6 \cdot 10^{-4}$ and $K_2 = 3 \cdot 10^{-8}$. It can therefore be shown that lead hydroxide is only partly dissociated in saturated solution. Applying the solubility of this hydroxide and its dissociation constants, we have calculated the solubility product of $Pb(OH)_2$ and have obtained a value of $8.17 \cdot 10^{-17}$. Finally, the solubility product (SP) can be calculated if we know the pH of the lead salt solution at the start of formation of $Pb(OH)_2$:

$$[Pb^{\cdot\cdot}][OH']^2 = SP \text{ or } \frac{[Pb^{\cdot\cdot}]I^2_{H_2O}}{[H^{\cdot}]^2} = SP$$

hence:

$$\log SP = \log[Pb^{\cdot\cdot}] + 2\log I_{H_2O} - 2\ \ [H^{\cdot}] \text{ or } \log SP = \log[Pb^{\cdot\cdot}] - 2pI_{H_2O} + 2pH.$$

For the purpose, therefore, of calculating the solubility product we must know the pH at the start of precipitation of the hydroxide and the concentration of lead ions at that instant. We could not find accurate data on this problem in the literature. In the majority of papers the pH at the start of precipitation of the hydroxide is given without indication of the corresponding concentration of the lead salt, and only in one instance [6] is it noted that lead hydroxide begins to come down from 0.02 molar lead nitrate solution at an approximate pH of 6. On this basis calculation gives a value of $SP = 2 \cdot 10^{-18}$. It is understood that this value must likewise be considered approximate. These data show that the solubility product of $Pb(OH)_2$ must be considerably lower than the values given in the literature.

With the aim of more accurate determination of the solubility product of lead hydroxide we performed a series of investigations which involved determination of the pH of the solution at the instant of formation of the hydroxide, using solutions of various ionic strengths. The pH was determined potentiometrically with the help of a quinhydrone electrode accurate to ± 0.01 pH.

To 5 ml of lead nitrate solution of definite concentration was added, from a microburet, an 0.01 N solution of sodium hydroxide free from carbonate; the pH of the solution was measured after addition of each portion of alkali and mixing. As an example we give the results of a series of experiments with 0.05 M solution of lead nitrate (Table 1).

TABLE 1

Experiments with 5 ml of 0.05 M Lead Nitrate Solution at 22°

Volume of 0.01 N NaOH solution added (ml)	0	0.05	0.10	0.15	0.20	0.30	0.40	0.50
pH	4.59	4.66	4.82	4.94	5.03	5.09	5.10	5.11

A graph of pH of solution versus volume of alkali solution added was plotted from the data obtained. The start of precipitation of hydroxide is given by the point at which an inflection of the curve is observed; in the present case the pH at the start of precipitation was 5.03. The lead ion concentration at that instant was $\frac{0.05 \cdot 5}{5.20} = 0.048$ g-ion/l and $\log [Pb^{\cdot\cdot}] = \bar{2}.68$.

Consequently:

$$\log SP = \hat{2}.68 - 2 \cdot 14 + 2 \cdot 5.03 = \overline{20}.74.$$

Hence:

$$SP = 5.5 \cdot 10^{-20}.$$

We repeated these measurements with 0.05 M lead nitrate solutions containing various amounts of cadmium nitrate (Table 2), i.e., with solutions with identical lead ion concentrations but with various ionic strengths (μ).

For the determination of the solubility product, or, more correctly, the activity product* in saturated $Pb(OH)_2$ solution, it is necessary to find this magnitude at an ionic strength substantially equal to zero. The solubility of $Pb(OH)_2$ is so small that the ionic strength of a saturated solution is very close to zero. From the data of Table 2 we constructed a graph of the solubility product as a function of the ionic strength and we extrapolated to zero ionic strength. In this manner we find that the solubility product at zero ionic strength or the activity product is equal to $1.1 \cdot 10^{-20}$ ($-\log SP = 19.96$).

TABLE 2

Determination of Solubility Product of $Pb(OH)_2$ in Solutions of Various Ionic Strengths at 22°.

Initial concentration (M/l)		Concentration at start of precipitation (M/l)		μ	pH of solution at start of precipitation of $Pb(OH)_2$	Sp of lead hydroxide	−log SP
$Pb(NO_3)_2$	KNO_3	$Pb(NO_3)_2$	KNO_3				
0.05	0	0.048	0	0.144	5.03	$5.5 \cdot 10^{-20}$	19.26
0.05	0.04	0.049	0.039	0.186	5.17	$1.05 \cdot 10^{-19}$	18.98
0.05	0.08	0.049	0.078	0.225	5.29	$1.82 \cdot 10^{-19}$	18.74
0.05	0.12	0.05	0.12	0.270	5.38	$2.81 \cdot 10^{-19}$	18.56
0.05	0.18	0.05	0.18	0.330	5.52	$5.49 \cdot 16^{-19}$	18.26

Similar measurements were made at 40° and 60° (Table 3).

TABLE 3

Determination of Solubility Product of Lead Hydroxide at 40 and 60°

Conc. at start of precipitation (M/1)		μ	pH of solution at start of precipitation	SP of lead hydroxide	−log SP	Note
$Pb(NO_3)_2$	KNO_3					
0.048	0	0.144	4.76	$2.3 \cdot 10^{-19}$	18.64	40°
0.048	0.039	0.183	4.82	$3.1 \cdot 10^{-19}$	18.51	$I^{40}_{H_2O} = 10^{-13.42}$
0.048	0.078	0.222	5.00	$6.9 \cdot 10^{-19}$	18.16	
0.048	0.118	0.262	5.13	$1.26 \cdot 10^{-18}$	17.90	
0.049	0.176	0.323	5.31	$2.92 \cdot 10^{-18}$	17.51	
0.048	0	0.144	4.24	$2.3 \cdot 10^{-19}$	18.64	60°
0.048	0.039	0.183	4.32	$3.39 \cdot 10^{-19}$	18.47	$I^{60}_{H_2O} = 10^{-12.9}$
0.049	0.078	0.225	4.61	$1.29 \cdot 10^{-18}$	17.89	
0.049	0.116	0.263	4.70	$1.90 \cdot 10^{-18}$	17.72	
0.049	0.175	0.322	4.82	$3.31 \cdot 10^{-18}$	17.48	

Graphical extrapolation to zero ionic strength leads to the following values of the activity product of lead hydroxide:

at 22° . . . $1.1 \cdot 10^{-20}$,
at 40° . . . $3.2 \cdot 10^{-20}$,
at 60° . . . $3.5 \cdot 10^{-20}$.

SUMMARY

1. The activity products of lead hydroxide were determined at 22, 40 and 60°. It was shown that these values slightly increase with rising temperature.

2. The activity product of lead hydroxide at 22-60° is $1.1{-}3\ 5 \cdot 10^{-20}$.

3. The change of ionic strength of the solution has a considerable influence upon the solubility product

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* $[Pb^{\cdot\cdot}][OH']^2 f_{Pb^{\cdot\cdot}} f^2_{OH'} = P_a$ or $SP f_{Pb^{\cdot\cdot}} f^2_{OH'} = P_a$, where P_a is the activity product, a constant magnitude at the given temperature; SP is the solubility product, a magnitude depending on the temperature and the ionic strength of the solution; f is the activity coefficient.

of lead hydroxide; this effect is intensified with rising temperature.

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PHYSICO-CHEMICAL ANALYSIS OF SYSTEMS OF THE HALIDES OF MERCURY, THE ALKALI METALS AND AMMONIUM

III. ELECTRICAL CONDUCTIVITY OF THE SYSTEMS $HgHa_2$–NH_4Ha IN MELTS

I. N. Belyaev and K. E. Mironov

In Communications I and II, data were presented for the fusibility of the systems $HgHa_2$–$MeHa$*. In the present communication we give results of an investigation of the electric conductivity of the systems $HgHa_2$–NH_4Ha.

The investigation of the electric conductivity of fused salt systems helps to add precision to data for the existence and composition of complex compounds detected by the fusibility method.

It was shown by the researches of A. G. Bergman and co-workers, Tarasova and others [1,2,3] that compounds detected on the liquidus line of the fusion diagram are characterized by sharp minima on the isotherms of specific electric conductivity of the melts. These sharp minima are observed both in the case of congruently and incongruently melting compounds. Depending upon the difference in magnitudes of the specific conductivity of the fused components, the minima on the conductivity isotherms are shifted more or less from the axis of composition of the compound in the direction of the less-conductive component [3].

Up to the present not more than two minima have been observed [3,4] on the isotherms of specific electric conductivity of fused binary systems, and indications have been obtained of a third minimum [14].

From this aspect great interest is attached to a study of the very intriguing chemistry of the system $HgHa_2$–NH_4Ha.

EXPERIMENTAL

Electric conductivities were measured in the apparatus previously described by one of us [5]. The cell was a modified Biltz cell of pyrex. It comprises four parts (Fig. 1): a small pipet with capillary a holds the internal electrode introduced into a glass tube. The outer electrode in the tube b and the thermocouple t (nichrome-constantan) are hermetically joined to a at point c with the help of an insulating disc** which ensured constant distance between the electrodes and permitted accurate measurement of the temperature of the melt. The cap d forced the cell into the test tube precisely to the stop piece e, thus enabling the maintenance of constant distance between the capillary of the pipet and the bottom of the test tube.

The electrodes were platinized to enable a sharp minimum in the sound in the earphones to be detected [6].

The cell constant was established against 0.1 N and 0.01 N NaCl solutions at 25° [4]. No corrections were made for the temperature. During the investigation the cell constant was systematically checked after 20-30 determinations. The temperature was determined by the method described in the preceding communications.

The test tube containing the cell was placed in a molybdenum glass casing immersed in a porcelain beaker containing a eutectic melt with the composition (weight-%) 44.9% KNO_3; 43.8% $Ca(NO_3)_2$; 11.3% $NaNO_3$. This melted at 133° and permitted heating to 450° [7,8]. Heating was performed in an electrical resistance furnace.

The large bulk of the eutectic melt (up to 2.5 kg) permitted smooth and gradual fall of temperature at the rate of 2-3° per minute.

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* Me = Na, K, NH_4; Ha = Cl, Br, I.

** The temperature for the systems $HgBr_2$ and HgI_2 was measured in this way; in the case of $HgCl_2$–NH_4Cl the thermocouple was placed between the test tube and the casing.

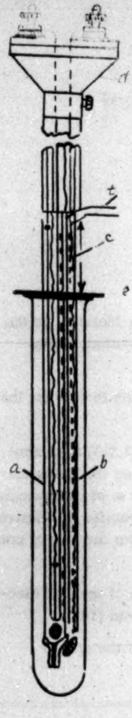

Figure 1. Cell for measurment of electric conductivity. Details in text.

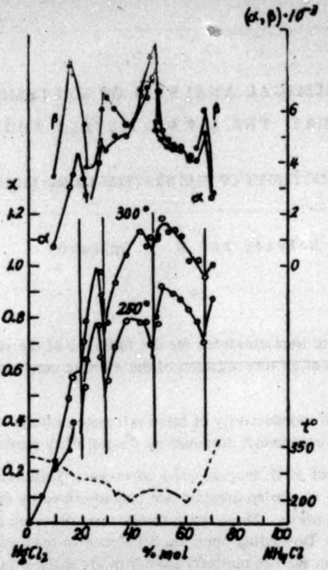

Figure 2. System $HgCl_2$—NH_4Cl. χ - specific electric conductivity: $\alpha\cdot10^{-3}$ and $\beta\cdot10^{-3}$ – its absolute and relative temperature coefficients.

The electric conductivities were measured polythermally and were extrapolated in some cases to 10-20°.

Isotherms through 25° were plotted from the polytherms.

On the basis of the isotherms the temperature coefficient of the specific electric conductivity through 50° was determined

$$\left(\text{absolute } \alpha = \frac{{}_2 - {}_1}{t_2 - t_1} \text{ and relative } \beta = \frac{\chi_2 - \chi_1}{t_2 - t_1} \cdot \frac{1}{\chi_{av.}}\right).$$

This added precision to the data for the existence of compounds [9, 10].

Agreement of a series of repeated measurements testified to the accuracy of the method.

The reagents used have been described before. The magnitudes of the specific electric conductivities of $HgCl_2$ and HgI_2 agreed with the handbook data [4]; we found for $HgBr_2$: χ_{235°* = $= 1.7\cdot10^{-4}$ ohm^{-1} cm^{-1}, instead of $\chi_{235^\circ} = 14.5\cdot10^{-4}$ ohm^{-1} cm^{-1}; according to Biltz the melting point is 243° instead of 238° [11]. The lower specific electric conductivity and the higher melting point reflect the high purity of our preparation.

System $HgCl_2$– NH_4Cl

The fusibility of the system has been examined previously. The liquidus line has transition points at 243, 235, 214° with respective contents of 18.5, 23.5 and 33.5 mole-% NH_4Cl, corresponding to the compounds $9HgCl_2\cdot NH_4Cl$; $3HgCl_2\cdot NH_4Cl$; and $2HgCl_2\cdot NH_4Cl$. The compound $HgCl_2\cdot NH_4Cl$ is characterized by a flat maximum at 218° and 50 mole-%** NH_4Cl. The transition point of 243° and 66.6% NH_4Cl correspond to the compound $HgCl_2\cdot$ $\cdot 2NH_4Cl$.

The specific electric conductivity of the system was studied in the range 225-300°. The 225,250,275 and 300° isotherms were constructed from the data of 25 polytherms (Fig. 2, Table 1). Four minima appear on the specific conductivity isotherms, two of which are sharp at 30 and 49% NH_4Cl and correspond to the compounds $2HgCl_2\cdot NH_4Cl$ and $HgCl_2\cdot NH_4Cl$. These minima are reflected by sharp maxima on the curves of the temperature coefficients of the electric conductivity.

The third minimum, corresponding to the 9:2 compound, is not sharply developed on the conductivity isotherms but is represented by a sharp maximum on the temperature coefficient curves.

The position of the fourth minimum, on the conductivity isotherms corresponding to $HgCl_2\cdot 2NH_4Cl$, was

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* Data extrapolated to 15°.

** Mole-percentages are given throughout.

TABLE 1

Specific Electric Conductivity of the System $HgCl_2$–NH_4Cl

Expt. No.	NH_4Cl (%)	x 225°	250°	275°	300°	$\alpha \cdot 10^3$ 250-300°	$\beta \cdot 10^3$ 250-300°
1	0.0	–	–	–	0.000124	–	–
2	5.1	–	–	0.090	0.111	–	–
3	10.0	–	0.219	0.231	0.242	0.82	3.52
4	15.9	–	0.284	0.383	0.491	3.12	7.80
5	17.0	–	0.394	0.486	0.577	3.64	7.47
6	21.5	–	0.537	0.625	0.711	3.47	5.55
7	22.0	–	0.648	0.718	0.790	2.80	3.90
8	27.0	0.657	0.779	0.889	0.985	4.11	4.62
9	28.0	0.504	0.650	0.786	0.891	4.81	6.11
10	30.0	0.432	0.561	0.682	0.787	4.52	6.63
11	33.4	0.547	0.688	0.817	0.940	5.05	6.18
12	37.6	0.616	0.790	0.930	1.048	5.13	5.52
13	43.2	0.602	0.787	0.970	1.131	6.62	6.81
14	45.2	0.618	0.784	0.940	1.075	6.59	6.93
15	47.3	0.458	0.700	0.923	1.116	7.30	8.10
16	49.7	0.591	0.802	0.976	1.111	6.78	6.78
17	50.0	0.730	0.785	1.080	1.122	5.68	5.33
18	51.5	0.707	0.928	1.077	1.183	5.27	4.91
19	53.8	–	–	1.046	1.138	4.88	4.63
20	55.8	0.702	0.890	1.040	1.137	4.73	4.56
21	58.2	0.707	0.378	1.023	1.113	4.60	4.52
22	62.0	0.678	0.838	0.953	1.023	4.16	4.34
23	65.0	0.630	0.790	0.925	1.021	4.16	4.57
24	67.8	–	0.702	0.855	0.960	5.17	6.04
25	70.6	–	0.877	0.948	1.010	2.62	2.76

determined approximately since the high content of NH_4Cl prevented measurement of the electric conductivity.

The minima on the conductivity isotherms at 30 and 49% NH_4Cl are shifted from the axis of the abscissas in the direction of the less conductive component, $HgCl_2$, to the extent of 1-4%, in agreement with the literature data [3].

The displacement of the conductivity minima at 20 and 67.5% NH_4Cl from the abscissas in the direction of NH_4Cl and the scatter of the points in the 50-55% NH_4Cl region on the 300° isotherm are bound up with the fugacity of the components.

System $HgBr_2$–NH_4Br

Data for the fusibility of the system were presented in Communication II. On the liquidus line the following compounds were detected: $9HgBr_2 \cdot 2NH_4Br$; $3HgBr_2 \cdot 2NH_4Br$; $HgBr_2 \cdot NH_4Br$; and $HgBr_2 \cdot 2NH_4Br$, to which correspond the transition points at 222, 165, 201 and 266°, and the respective NH_4Br contents of 24.0, 40.0, 60.5 and 67.0%. The specific electric conductivity of the system was studied from 200 to 375°. The data from 33 polytherms were applied in plotting eight specific

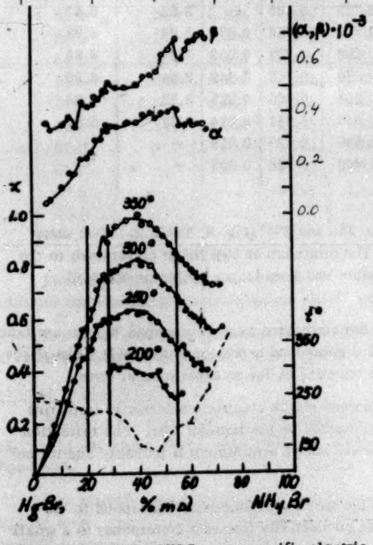

Fig. 3. System $HgBr_2$–NH_4Br. x – specific electric conductivity; $\alpha \cdot 10^{-3}$ and $\beta \cdot 10^{-3}$ are its absolute and relative coefficients.

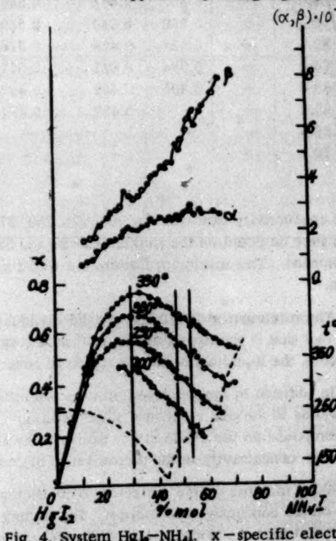

Fig. 4. System HgI_2–NH_4I. x – specific electric conductivity; $\alpha \cdot 10^{-3}$ – absolute coefficient; $\beta \cdot 10^{-3}$ – relative coefficient

TABLE 2

Specific Electric Conductivity of the System $HgBr_2$–NH_4Br

Prep. No.	NH_4Br	χ 200°	225°	250°	275°	300°	325°	350°	375°	α · 10³ 250-300°	β · 10³ 250-300°
1	0	–	–	0.026 · 10²	0.042	0.078	–	–	–	–	–
2	6.0	–	–	0.128	0.140	0.151	–	–	–	0.50	3.57
3	7.5	–	–	0.163	0.180	0.194	–	–	–	0.60	3.33
4	12.0	–	–	0.287	0.320	0.340	–	–	–	1.12	3.50
5	15.0	–	0.315	0.368	0.417	0.455	–	–	–	1.60	3.84
6	17.0	–	0.378	0.425	0.469	0.503	–	–	–	1.62	3.46
7	19.0	–	0.400	0.454	0.510	0.565	0.618	–	–	2.23	4.37
8	21.1	–	0.425	0.486	0.545	0.602	0.655	–	–	2.30	4.22
9	22.5	–	0.451	0.522	0.586	0.642	0.691	–	–	2.49	4.24
10	24.0	–	0.485	0.568	0.645	0.712	0.770	–	–	2.90	4.53
11	26.0	–	0.498	0.583	0.665	0.743	0.805	0.845	–	3.00	4.50
12	27.5	–	0.520	0.600	0.682	0.763	0.832	0.910	–	3.28	4.81
13	28.5	–	0.500	0.587	0.672	0.751	0.829	0.897	–	3.26	4.85
14	29.0	0.395	0.493	0.590	0.681	0.767	0.837	0.902	–	3.50	5.12
15	30.0	0.424	0.517	0.607	0.693	0.778	0.858	0.930	–	3.43	4.95
16	32.0	0.412	0.518	0.610	0.699	0.786	0.872	0.958	–	3.46	4.95
17	36.0	0.426	0.534	0.629	0.718	0.805	0.891	0.978	–	3.59	5.00
18	40.0	0.398	0.517	0.621	0.723	0.824	0.917	1.003	–	3.62	5.01
19	42.0	0.394	0.510	0.623	0.717	0.805	0.883	0.963	–	3.84	5.33
20	45.0	0.385	0.503	0.607	0.713	0.804	0.887	0.965	–	3.90	5.45
21	47.5	0.395	0.498	0.588	0.680	0.766	0.856	0.943	–	3.80	5.58
22	50.0	0.336	0.436	0.542	0.638	0.734	0.828	0.914	–	3.92	6.27
23	52.5	0.307	0.412	0.517	0.623	0.716	0.805	0.887	–	4.03	6.47
24	55.0	0.297	0.390	0.488	0.582	0.682	0.768	0.852	–	4.02	6.85
25	57.0	0.317	0.404	0.492	0.578	0.666	0.745	0.822	–	3.50	6.06
26	59.0	–	0.383	0.461	0.548	0.636	0.723	0.805	–	3.52	6.41
27	60.5	–	0.352	0.440	0.528	0.619	0.704	0.786	0.874	3.60	6.73
28	62.0	–	0.339	0.428	0.516	0.603	0.688	0.772	0.859	3.54	6.80
29	64.0	–	0.334	0.421	0.507	0.594	0.676	0.759	0.842	3.54	6.99
30	65.0	–	0.305	0.402	0.497	0.594	0.685	0.760	0.825	3.53	7.08
31	67.0	–	–	0.402	0.484	0.566	0.647	0.731	0.814	3.32	6.87
32	69.0	–	–	–	–	0.552	0.638	0.727	0.818	–	–
33	72.0	–	–	–	–	0.569	0.648	0.726	0.807	–	–

electric conductivity isotherms for 200, 225, 250, 275, 300, 325, 350 and 375° (Fig. 3, Table 2). Two sharp minima were detected on the isotherms at 30 and 55% NH_4Br. The minimum at 55% NH_4Br corresponds to the 1:2 compound. This minimum flattens out with rising temperature and is no longer visible on the 300° isotherm.

The minimum at 30% NH_4Br on the liquidus curve does not correspond to any compound, but its existence and the fact that it persists on all the isotherms suggest that a 2:1 compound is present in the melt. The slight inflection of the liquidus line in this region of concentrations is regarded as due to experimental error.

In addition to the described minima, an inflection is observed on the electric conductivity isotherms corresponding to the 9:2 compound which is fairly clearly characterized on the liquidus line. The reflection of this compound on the conductivity isotherms by an inflection and not by a minimum is probably due to the sharp rise in conductivity in the narrow range of concentration.

Sharp maxima on the temperature coefficient curves of the specific conductivity correspond to the minima on the conductivity isotherms. The turning point on the conductivity isotherm corresponds to a small sharp maximum on the temperature coefficient curves.

TABLE 3

Specific Electric Conductivity of the System $HgBr_2$–NH_4Br

Expt. No.	NH_4I %	$\varkappa$							$\alpha \cdot 10^3$	$\beta \cdot 10^3$
		200°	225°	250°	275°	300°	325°	350°	250-300°	250-300°
1	0.0	–	–	–	0.0310	0.0285	0.0275	0.0260	–	–
2	6.0	–	–	–	0.259	0.263	0.267	0.270	–	–
3	12.0	–	–	0.407	0.428	0.442	0.456	0.465	0.72	1.68
4	14.0	–	–	0.442	0.467	0.484	0.500	0.514	0.84	1.79
5	16.0	–	–	0.487	0.516	0.535	0.559	0.578	0.94	1.83
6	18.0	–	–	0.510	0.543	0.573	0.598	0.623	1.24	2.28
7	21.0	–	0.494	0.538	0.578	0.613	0.646	0.672	1.48	2.56
8	22.5	–	0.500	0.552	0.594	0.633	0.668	0.695	1.63	2.75
9	25.0	0.464	0.518	0.567	0.611	0.653	0.690	0.720	1.73	2.84
10	27.0	0.453	0.514	0.566	0.615	0.661	0.700	0.736	1.86	3.02
11	28.5	0.449	0.511	0.566	0.618	0.667	0.711	0.748	2.07	3.51
12	30.0	0.443	0.507	0.564	0.618	0.667	0.712	0.751	2.13	3.40
13	31.5	0.453	0.512	0.567	0.622	0.668	0.714	0.753	2.03	3.26
14	33.0	0.446	0.506	0.567	0.616	0.668	0.725	0.756	2.07	3.36
15	35.0	0.422	0.487	0.552	0.613	0.663	0.713	0.754	2.21	3.61
16	37.0	0.408	0.474	0.535	0.593	0.650	0.702	0.747	2.30	3.88
17	38.5	0.390	0.458	0.523	0.588	0.647	0.702	0.740	2.44	4.15
18	40.0	0.367	0.442	0.512	0.577	0.636	0.687	0.727	2.42	4.21
19	42.5	0.353	0.422	0.490	0.555	0.616	0.673	0.715	2.52	4.49
20	44.0	0.348	0.416	0.480	0.544	0.604	0.660	0.704	2.44	4.49
21	45.0	0.327	0.400	0.466	0.530	0.592	0.643	0.691	2.50	4.62
22	46.5	0.323	0.392	0.457	0.519	0.578	0.635	0.680	2.43	4.62
23	48.0	0.280	0.358	0.424	0.493	0.555	0.613	0.669	2.62	5.33
24	49.0	0.298	0.362	0.426	0.490	0.551	0.611	0.661	2.50	5.10
25	50.5	0.275	0.348	0.415	0.484	0.546	0.602	0.652	2.66	5.51
26	52.0	0.258	0.324	0.394	0.463	0.528	0.592	0.648	2.75	5.94
27	53.0	0.240	0.305	0.372	0.443	0.510	0.572	0.628	2.80	6.31
28	54.0	0.224	0.298	0.372	0.449	0.524	0.588	0.640	3.00	6.67
29	55.5	0.236	0.302	0.365	0.432	0.502	0.563	0.620	2.62	6.12
30	57.5	0.208	0.281	0.348	0.420	0.488	0.553	0.607	2.79	6.65
31	58.0	0.194	0.260	0.328	0.398	0.465	0.533	0.601	2.73	6.83
32	62.5	–	–	0.304	0.368	0.437	0.505	0.575	2.70	7.36
33	65.0	–	–	0.283	0.355	0.424	0.493	0.557	2.63	7.98
34	67.5	–	–	0.248	0.324	0.398	0.470	0.543	–	–
35	70.0	–	–	0.276	0.339	0.402	0.468	0.534	–	–

From the character of the conductivity isotherms (particularly the 300° isotherm) we may expect a minimum corresponding to the compound $HgBr_2 \cdot 4NH_4Br$.

It was not possible to establish its position accurately because of the very small difference in melting and boiling points of mixtures of this composition.

System HgI_2–NH_4I

The liquidus lines in this system pointed to the existence of two incongruently melting compounds, $HgI_2 \cdot 2NH_4I$ and $HgI_2 \cdot 4NH_4I$, with transition points at 210 and 234° and with NH_4I contents of ,respectively, 60 and 63%.

The electric conductivity of the system was studied by the plotting of 35 polytherms from which were prepared seven specific conductivity isotherms for 200, 225, 250, 275, 300, 325 and 350° (Fig. 4 and Table 3). The 200° isotherm contains three sharp minima at 30, 48 and 53% NH_4I, only one of which (53%) corresponds to a chemical compound detected on the liquidus line during investigation of the fusibility. The two other minima at 30 and 48% NH_4I are not reflected by any inflections on the liquidus curve, but their presence on the conductivity isotherms points to the occurrence of chemical reaction in the melts. Compounds are here possibly formed with the composition $2HgI_2 \cdot NH_4I$ and $HgI_2 \cdot NH_4I$. Both of these minima flatten out with rising temperature and are no longer present on the 350° isotherm. All the minima on the conductivity isotherms of the system are reflected by sharp maxima on the temperature coefficient curves.

In the concentration region corresponding to the compound $HgI_2 \cdot 4NH_4I$, indicated on the liquidus line in the form of a crystallization branch between 210 and 234°, the electric conductivity was not investigated due to the very small melting point and boiling point differences of the mixtures close to the composition of this compound. Judging, however, by the character of the 250 and 300° isotherms in the region of 65-70% NH_4I, a minimum on the conductivity isotherms corresponding to this compound can be expected.

The first conspicuous feature observed on comparing the specific conductivity data of the above systems is the trend of change in the general character of the conductivity isotherms in the series Cl–Br–I. In the system $HgCl_2$–NH_4Cl the isotherms have a general rise from $HgCl_2$ to NH_4Cl, the values of the minima of the specific electric conductivity rise with the NH_4Cl concentration. In the system $HgBr_2$–NH_4Br a general rise of the isotherms is only observed up to 45% NH_4Br, after which the isotherms are bent toward the composition abscissas. In this region the values of the electric conductivity are lower at the minima than the values at the minima at the region of general rise of the isotherms. The fall in conductivity and the larger inclination of the isotherms to the composition abscissas starting from the general maximum is even more marked in the system HgI_2–NH_4I with rise of MeHa concentration.

The above-mentioned change in the general character of the conductivity isotherms in the series Cl–Br–I is closely associated with the fall in conductivity of MeHa in this series [4] and with the increased tendency to form compounds richer in NH_4 in the order Cl, Br, I; this leads to nonuniform change of conductivity of the resultant complex ions in the systems $HgHa_2$–NH_4Ha. Whereas in the system $HgCl_2$–NH_4Cl the conductivity of the formed complex ions increased with falling $HgCl_2$ content, in the system HgI_2–NH_4I the conductivity of the formed ions, starting from the general maximum on the conductivity isotherms (25%), should decrease with rising NH_4I content of the complex.

The character of the minima on the conductivity isotherms and of the maxima on the temperature coefficient curves is very clear-cut in the system $HgCl_2$–NH_4Cl, and the decreasing sharpness in the order Br, I confirms the previous conclusion about the increased susceptibility to complex formation and the increased stability of the complexes in the order I, Br, Cl with one and the same cation of alkali metal or ammonium.

Not more than two sharp minima on the conductivity isotherms have hitherto been detected [4,13] in studies of the electric conductivity of binary salt systems in melts, and there have been indications of a third one [12]. In the present investigation we succeeded in obtaining four sharp minima on the specific electric conductivity isotherms and the corresponding maxima on the temperature coefficient curves.

In the system $HgCl_2$–NH_4Cl in the low-concentration region, Foote and Martin [14] indicate the possibility of existence only of the complex $HgCl_2 \cdot NH_4Cl$. Our data for fusibility and electric conductivity indicate the existence of complexes richer in $HgCl_2$.

The most stable type of complex in a melt is $2HgHa_2 \cdot MeHa$, which is observed in all cases even when it does not appear on the liquidus line.

SUMMARY

1. The specific electric conductivity of the systems $HgCl_2$–NH_4Cl, $HgBr_2$–NH_4Br and HgI_2–NH_4I in melts has been investigated.

2. The electric conductivity method has confirmed that in melts the susceptibility to formation of complexes between $HgHa_2$ and MeHa increases in the order I, Br, Cl. The stability of the formed complexes also increases in that order.

3. For the first time isotherms of the specific electric conductivity of binary salt systems in melts have been obtained with four minima. On the temperature coefficient curves these minima are reflected by corresponding sharp maxima.

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HIGHER MOLECULAR COMPOUNDS IN THE SYSTEM $CdCl_2$–KCl–H_2O

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In previous researches one of us showed [1] that by applying N. S. Kurnakov's principle of physicochemical analysis we can use refractometric data to establish the possible formation and to determine the molecular composition of higher molecular compounds in salt mixtures.

Among the physicochemical methods(utilizing heats of mixing, depression, electric conductivity, density, etc.) used for establishing the existence of molecular compounds in solutions, refractometry is one of the most accurate and convenient methods; on the basis of deviations from additivity of the refractive indices we can draw conclusions about the amount and form of molecular compounds formed in a solution of a given salt mixture.

Measurement of the refractive indices of salt mixtures (or measurement of any other physical constant) and comparison of the values with those theoretically calculated from the additivity law enables us, from the additivity deviation Δ_n, to infer the formation of higher molecular compounds from the components of the salt mixture. The composition of the chemical compound corresponds to a maximum or minimum on the curve of Δ_n versus composition of the mixture.

On the basis of the additivity law it is easy to calculate the theoretical value of the refractive index of a mixture (n-theoretical) from the usual formula:

$$\frac{\alpha \cdot n_{\alpha} + \beta n_{\beta}}{\alpha + \beta} = n_{\text{theor.}},$$

where α = weight in grams of initial solution of one salt;
n_{α} = refractive index of the same starting solution;
β = weight in grams of starting solution of the second salt;
n_{β} = refractive index of the initial solution of the second salt.

The number of maxima or minima on the additivity deviation curve (Δ_n) permits an evaluation of the number of different forms of molecular compounds formed in a solution of the given salt mixture.

By applying certain optical methods, for instance photocolorimetry, it is believed [2] that the one most stable form of higher molecular compound can be detected, although for a given pair of salts several forms of molecular compounds may be formed in solution, as established by other physicochemical methods.

On the other hand, Babko [5] made extensive use of optical methods and of photometry in particular (change of extinction of solutions, measurement of the absorption spectra of complex groups) for determination of the dissociation constants (bond energies) and of the composition of complex compounds.

Vosburgh and Cooper [3], at first theoretically and later experimentally, showed that not one but several possible forms of higher compounds could be identified by the method of light absorption using a light filter to cut out all but a specific wave-length region.

As a check on the validity of the method we have carried out a refractometric study of the possibility of formation of molecular compounds in the system $CdCl_2$–KCl–H_2O, in which the first component ($Cd^{\cdot\cdot}$) is a good complex-former known to yield not only ordinary higher molecular compounds with halogen addenda such as $M[CdHa_3]$ to $M_4[CdHa_6]$, but also autocomplexes of the type of $Cd[CdI_3]_2$, where M = metal.

EXPERIMENTAL

The starting solutions were prepared from chemically pure (guaranteed) $CdCl_2$ and KCl by solution of the calculated amount of salt in a weighed amount of water to give the required molar concentrations.

The salt content of the solution was later checked by titration.

Mixtures were prepared from the starting solutions by adding to a previously calculated and weighed amount of the solution of one component a calculated and weighed amount of solution of the second.

In this manner we avoid the errors admitted by Spacu and Popper [4] when they prepared the starting solutions by weight but prepared the salt mixtures by volume without considering that the weighed amounts are not volumetrically equivalent, and thus arrived at erroneous conclusions about the forms of the molecular compounds.

Since the weights of both of the starting materials are known, then from determinations of each of their indices of refraction we can calculate (on the basis of the additivity law) the theoretical values of the refractive indices ($n_{theor.}$) from the above formula.

Hence for each mixture we find the difference:

$$\Delta_n = n_{theor.} - n_{exp.}$$

If we now plot on the abscissas the composition of the mixture and along the ordinates the correspondingly determined deviations from additivity of the refractive indices (Δ_n); then we obtain a graph in which the maxima or the minima of the deviations from additivity correspond to the higher molecular compounds whose composition we find at the point on the abscissa opposite to the maximum or minimum on the curve of Δ_n versus composition of mixture.

As previously [1], the refractive indices were measured with the help of a Pulfrich immersion refractometer. The determinations were accurate to ± 0.05 scale divisions, corresponding to ± 1.82 units in the fifth place of the refractive index.

In the determinations of the refractive indices of the solutions use was made of three interchangeable prisms of the refractometer which served to cover the whole range of the change of refractive indices of the solutions of our salt mixtures:

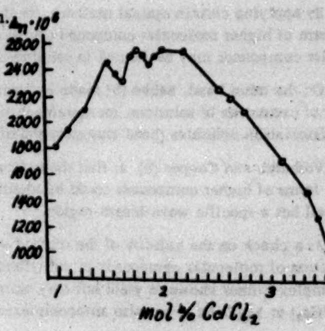
1) prism 1 – n_D from 1.3254 to 1.3664,
2) " 2-L – n_D " 1.3642 to 1.3990,
3) " 3-L – n_D " 1.3989 to 1.4360.

Prism 1 was checked against distilled water, the two others with the help of special plates.

Concordant data were obtained by carefully adjusting the refractometer for each set of prisms.

During the refractometric determinations the temperature of the solutions was kept constant at 20°C ±0.02° with the help of an ultrathermostat. Measurements were performed under conditions excluding evaporation of the solvent.

Data are presented in Tables 1 and 2 and in the diagram.



System $CdCl_2 - KCl - H_2O$.

TABLE 1

System $CdCl_2$–KCl–H_2O (Starting Solutions)

Name	Mole-%	Molarity per 1000 g	Molecular weight	n_D^{20}
$CdCl_2$	4.4264	1.7473	183.324	1.392379
KCl	4.4215	2.1552	74.553	1.354898

In the system $CdCl_2$–KCl–H_2O the deviations from additivity of the refractive indices differ fundamentally from those observed by us for ternary systems [1] where the complex-formers were ions of alkali earth metals and magnesium. For the systems

$MgCl_2$–KCl–H_2O,
$SrBr_2$–NH_4Cl–H_2O,
$BaCl_2$–KCl–H_2O

TABLE 2

Mixtures of Solutions of $CdCl_2$ and KCl

Expt. No.	Mole-% $CdCl_2$	Mole-% KCl	Mole-% Total	Mole-% H_2O	$n^{20}_{\text{theor.}}$	$n^{20}_{\text{exp.}}$	$\Delta\eta\ 10^6$	$CdCl_2/KCl$
1	0,9833	3.4422	4.4255	95,5745	1.364672	1,362859	1813	1:3.5
2	1.1069	3,3198	4.4267	95,5733	1.365822	1,363881	1941	1:3
3	1.2656	3.1598	4.4254	95.5748	1.367295	1,365200	2095	1:2.5
4	1.4755	2,9510	4,4265	95,5735	1,369205	1,366760	2445	1:2
5	1.5603	2,8605	4.4208	95.5692	1.369976	1,367613	2363	1:1.83
6	1.6462	2.7811	4,4273	95,5727	1.370790	1.368476	2314	1:1.75
7	1.7069	2.7133	4.4202	95.5798	1.371286	1.368799	2487	1:1.59
8	1.7710	2.6515	4.4225	95,5775	1.371821	1.369292	2529	1:1.5
9	1.8272	2.5961	4.4233	95.5767	1.372320	1.369812	2508	1:1.42
10	1.8801	2.5402	4.4203	95,5797	1,372791	1.370356	2435	1:1.35
11	1.9444	2.4801	4.4205	95.5795	1.373350	1.370862	2488	1:1.22
12	2,0172	2.4114	4.4286	95,5714	1.373903	1.371366	2537	1:1.2
13	2,2102	2.2102	4,4204	95.5796	1.375607	1.373080	2527	1:1
14	2.5417	1,8813	4.4230	95,5770	1.378314	1.376076	2238	1.35:1
15	2.6546	1.7723	4.4269	95,5731	1.379269	1,377093	2176	1.5:1
16	2.7756	1,6484	4.4240	95.5760	1,380216	1.378149	2067	1.75:1
17	3.1608	1.2670	4.4278	95,5722	1.383192	1.381502	1690	2.5:1
18	3.3207	1.1068	4.4275	95.5725	1.384410	1.382962	1448	3:1
19	3.4430	0.9827	4.4257	95.5743	1.385328	1.384063	1265	3.5:1
20	3.5421	0.8854	4.4275	95,5726	1.386068	1.385052	1016	4:1

we always observed only one maximum, corresponding to the 1:1 composition, on the Δ_n/composition plot.

In the present case (Table 2 and diagram) the $\Delta\eta$/composition plot exhibits deviation from additivity represented by three maxima to which correspond mixtures of salts in the respective molar ratios of 1:1, 1:1.5 and 1:2.

Consequently in the case of the ternary system $CdCl_2$–KCl–H_2O we have detected molecular compounds with the compositions:

$1CdCl_2$: 1KCl, which corresponds to the composition $K[CdCl_3]$,
$1CdCl_2$: 1.5KCl, " " " " $2CdCl_2 \cdot 3KCl$,
$1CdCl_2$: 2KCl, " " " " $K_2[CdCl_4]$.

Spacu and Popper [4] also studied higher molecular compound formation in this system on the basis of refractive index changes in the mixtures, but they applied Job's [2] principle of continuous changes for the calculations, apart from which (as noted above) they prepared their starting solutions by weight and the mixtures by volume so that the results were confused by the nonequivalence between the gravimetric and volumetric data as well as by the differing densities of the starting solutions.

For the system $CdCl_2$–KCl–H_2O they claimed the formation of compounds not entirely identical with ours.

They obtained the following compounds:

$CdCl_2$: KCl = 1:1, corresponding to the composition $K[CdCl_3]$,
$CdCl_2$:KCl = 1:2, " " " $K_2[CdCl_4]$,
$CdCl_2$:KCl = 1:3, " " " $K_3[CdCl_5]$.

In view of the inaccuracy admitted by Spacu and Popper we made a recalculation of their data for the expression of the molarity of their solutions per 1000 g; the following values were obtained (Tables 3,4 and 5).

SUMMARY

The system $CdCl_2$–KCl–H_2O was studied by the method of physico-chemical analysis by measurement of the refractive indices of the solutions with the aim of establishing the possibility of formation of higher molecular compounds in solution.

TABLE 3

Starting solutions

Name	Molecular weight	Molarity per 1000 g solution	d_4^{20}	n^{20}	Molarity recalculated per 1 liter of solution
$CdCl_2$	183.324	2.0041	1.43039	1.404044	2.8664
KCl	74.553	1.9918	1.09685	1.352904	2.1847

TABLE 4

Mixtures of Solutions of $CdCl_2$ and KCl (Data of Spacu and Popper)

$CdCl_2$ + KCl (cm^3)	C (%)	n^{20}	d_4^{20}	$R_{exp.}$	$R_{theor.}$	$\Delta n \cdot 10^5$	C_{CdCl_2} (%)	C_{KCl} (%)
12+ 8	29.34	1.38336	1.29739	0.117755	0.118262	50.7	25.61	6.64
11+ 9	28.31	1.380752	1.28074	0.118903	0.119534	63.1	23.99	7.39
10+10	27.25	1.378150	1.26044	0.120190	0.120910	72.0	22.23	8.14
9+11	26.16	1.375516	1.246852	0.121845	0.122465	62.0	20.44	8.87
8+12	25.04	1.372985	1.230526	0.123355	0.124168	83.0	18.57	9.58
7+13	23.88	1.370367	1.213630	0.125247	0.126109	86.2	16.61	10.28
6+14	22.70	1.367802	1.196640	0.127554	0.128274	72.0	14.56	10.97
5+15	21.48	1.365221	1.17922	0.129940	0.130750	81.0	12.42	11.65
4+ 16	20.24	1.362590	1.163080	0.132899	0.133619	72.0	10.18	12.31

TABLE 5

Mixtures of $CdCl_2$ and KCl

Mixture No.	$CdCl_2$ + KCl (cm^3)	$CdCl_2$:KCl (cm^3)	Formulas of higher order compounds according to Spacu and Popper	$CdCl_2$–KCl (in moles 10^{-2})	$CdCl_2$:KCl (in moles)	Formulas of higher order compounds after recalculation	$\Delta n \cdot 10^5$ on curve
1	12+ 8	1.5 :1		3.44+1.746	1.97:1		50.7
2	11+ 9	1.22:1		3.15+1.964	1.61:1		63.1
3	10+10	1:1	$CdCl_2$:KCl	2.87+2.183	1.31:1	≃ $CdCl_2$:KCl	72.0
4	9+11	1:1.22		2.58+2.40	1.07:1		62.0
5	8+12	1:1.5		2.29+2.62	1:1.14		83.0
6	7+ 13	1:1.86	$CdCl_2$:2KCl	2.01+2.836	1:1.41	≃ $CdCl_2$: 1.5KCl	86.2
7	6+14	1:2.33		1.72+3.055	1:1.77		72.0
8	5+ 15	1:3	$CdCl_2$:3KCl	1.43+3.274	1:2.29	≃ $CdCl_2$:2KCl	81.0
9	4+16	1:4		1.147+3.49	1:3.04		72.0

1. The deviations from additivity of the refractive indices of solutions of salts in the system $CdCl_2$–KCl–H_2O demonstrated the existence of higher molecular compounds of the following compositions: K[$CdCl_3$]; 2$CdCl_2$ · 3KCl; K_2[$CdCl_4$].

2. The refractometric method succeeded in showing the presence in solution of not only one but of several possible molecular compounds.

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* See Consultants Bureau translation, p. 31.

DOUBLE DECOMPOSITION IN THE RECIPROCAL SYSTEM OF THE SULFATES AND TUNGSTATES OF SODIUM AND LEAD[*]

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This investigation is one of a series on the study of complex formation and double decomposition in the reciprocal systems of the sulfates, molybdates and tungstates of sodium, potassium and lead in melts. The investigation was performed by the visual-polythermic method of physicochemical analysis described by many authors [1]. Mixtures of the salts were melted in a platinum crucible in a crucible resistance furnace, temperatures were measured with a platinum – platinum-rhodium thermocouple with a φ galvanometer, calibrated in the usual manner against the melting points of the chemically pure salts. The liquidus curves were plotted from the temperatures of appearance of the first crystals. For melts close to the invariant point the temperatures of complete setting were determined.

The following salts were used: Sodium sulfate, m.p. 884°; sodium tungstate, m.p. 695°; lead sulfate and tungstate prepared in the laboratory from dilute solutions of chemically pure, soluble salts of lead, sulfuric acid and sodium tungstate. Melts of the mixtures of the salts were perfectly transparent.

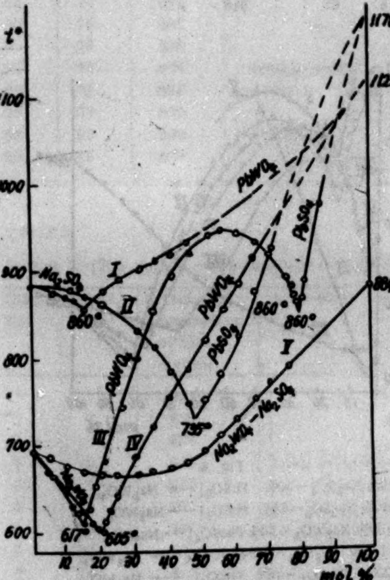

Fig. 1.

Sections: Na_2SO_4–$PbSO_4$ (II); Na_2WO_4–$PbWO_4$ (IV); Na_2WO_4–Na_2SO_4 (V); and diagonal sections: Na_2WO_4–$PbSO_4$ (III), Na_2SO_4–$PbWO_4$ (I).

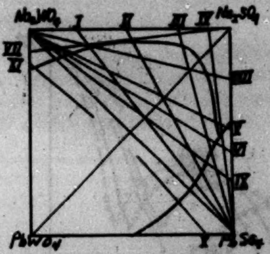

Fig. 2. Distribution of internal sections in the square of the reciprocal system.

Sides: Three out of the four sides have been investigated by other authors [2]: Na_2SO_4–$PbSO_4$, Na_2SO_4–Na_2WO_4 and $PbSO_4$–$PbWO_4$. The first two of these have been repeated. The system Na_2SO_4–$PbSO_4$ has a simple eutectic at 735° and 47% $PbSO_4$[**] (Figures 1, II). The system Na_2WO_4–Na_2SO_4 (Table 1, Figure 1, V) comprises a continuous series of solid solutions with a minimum at, according to our measurements, 670° in the range of 20 to 40% Na_2SO_4 (Boeke gives [2] 633°). Limited reciprocal solubility is shown in the system $PbSO_4$–$PbWO_4$ with a eutectic at 995° and 50% $PbSO_4$. Our investigation of

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[*] The investigation was carried out with the help of L. P. Nuzhnova.

[**] Molar percentages throughout.

TABLE 1

Fusibility of the System Na_2SO_4–Na_2WO_4

Expt. No.	Na_2WO_4 (%)	Temp. of appearance of first crystals	Solid phase
1	100	695	Na_2WO_4
2	95	688	$Na_2 \parallel WO_4, SO_4$
3	90	678	
4	85	672	
5	80	670	
6	75	670	
7	70	671	
8	65	672	
9	60	674	$Na_2 \parallel SO_4, WO_4$
10	55	684	
11	50	698	
12	45	715	
13	40	735	
14	35	755	
15	30	775	
16	25	792	

TABLE 2

Fusibility of the System Na_2SO_4–Na_2WO_4

Expt. No.	Na_2WO_4 (%)	Temp. of appearance of first crystals	Solid phase
1	0	695	Na_2WO_4
2	5	670	
3	10	648	
4	15	625	
5	18	615	
6	20	607	
7	20.5	605	Na_2WO_4, $PbWO_4$
8	21.5	614	$PbWO_4$
9	23	627	
10	25	645	
11	30	689	
12	35	724	
13	40	760	
14	45	790	
15	50	825	
16	55	860	
17	60	887	
18	65	918	

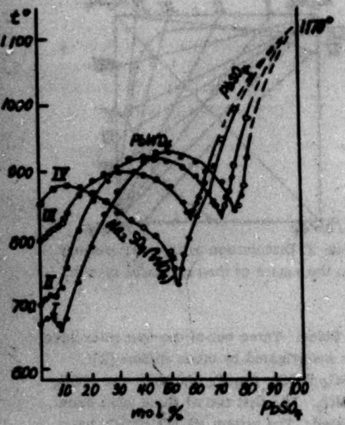

Fig. 3.

I) [75% Na_2WO_4 − 25% Na_2SO_4] → $PbSO_4$,
II) [50% Na_2WO_4 − 50% Na_2SO_4] → $PbSO_4$,
III) [25% Na_2WO_4 − 75% Na_2SO_4] → $PbSO_4$ and
IV) [90% Na_2SO_4 − 10% Na_2WO_4] → $PbSO_4$.

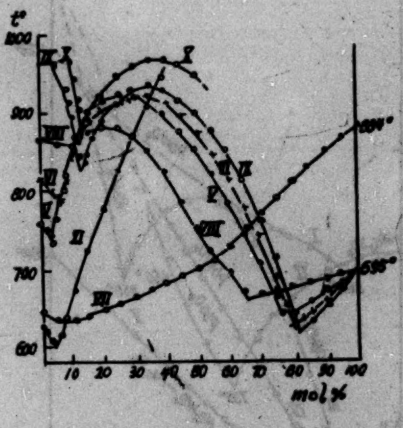

Fig. 4.

V) [50% Na_2SO_4 − 50% $PbSO_4$] → Na_2WO_4,
VI) [40% Na_2SO_4 − 60% $PbSO_4$] → Na_2WO_4,
VII) [90% Na_2WO_4 − 10% $PbWO_4$] → Na_2SO_4,
VIII) [75% Na_2SO_4 − 25% $PbSO_4$] → Na_2WO_4,
IX) [25% Na_2SO_4 − 75% $PbSO_4$] → Na_2WO_4,
X) [85% $PbSO_4$ − 15% $PbWO_4$] → Na_2WO_4,
XI) [15% $PbWO_4$ − 85% Na_2WO_4] → $PbSO_4$.

TABLE 3

Diagonal Section of Na_2WO_4–$PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	695	Na_2WO_4
2	5	668	$Na_2 \| SO_4, WO_4$
3	10	638	
4	12	628	
5	14	617	$Na_2 \| SO_4, WO_4, PbWO_4$
6	15	630	$PbWO_4$
7	18	658	
8	20	688	
9	25	748	
10	30	804	
11	35	860	
12	40	897	
13	45	925	
14	50	948	
15	55	952	
16	60	949	
17	65	936	
18	70	921	
19	75	895	
20	76	886	
21	77	876	$PbWO_4$, α–$PbSO_4$
22	78	868	α–$PbSO_4$
23	79	870	β–$PbSO_4$
24	80	890	
25	85	980	

TABLE 4

Diagonal Section of Na_2SO_4–$PbWO_4$

Expt. No.	$PbWO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	884	Na_2SO_4
2	5	883	
3	10	870	
4	12	872	
5	15	860	Na_2SO_4, $PbWO_4$
6	20	882	$PbWO_4$
7	25	898	
8	30	909	
9	35	916	
10	40	922	
11	45	932	
12	50	950	
13	55	962	
14	60	975	
15	65	990	

the system Na_2WO_4–$PbWO_4$ is the first to have been published. This system exhibits a simple eutectic at 605° and 25% $PbWO_4$ (Table 2, Figure 1, IV).

The crystallization surfaces of all the reciprocal systems were determined by an investigation of 2 diagonal and 11 internal sections. The distribution of the internal sections is represented in Figure 2.

TABLE 5

Section I – [75% Na_2WO_4 – 25% Na_2SO_4] ⟶ $PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	667	$Na_2 \| SO_4, WO_4$
2	1	672	
3	3	677	
4	5	678	
5	7	670	
6	10	675	
7	15	730	$PbWO_4$
8	20	785	
9	25	832	
10	30	869	
11	35	898	
12	40	916	
13	45	926	$PbWO_4$
14	50	928	
15	55	925	
16	60	916	
17	65	906	
18	70	884	
19	75	836	$PbWO_4$, x – $PbSO_4$
20	76	850	α – $PbSO_4$
21	77	864	
22	78	880	β – $PbSO_4$
23	80	924	

TABLE 6

Section II – [50% Na_2WO_4 – 50% Na_2SO_4] ⟶ $PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	690	$Na_2\|SO_4, WO_4$
2	2	704	
3	4	710	
4	5	712	
5	6	712	
6	7	708	$Na_2\|SO_4, WO_4 – PbWO_4$
7	8	724	$PbWO_4$
8	10	752	
9	15	810	
10	20	858	
11	25	888	
12	30	905	
13	35	918	
14	40	922	
15	45	922	
16	50	918	
17	55	908	
18	60	893	
19	65	867	
20	67	855	
21	68	846	
22	70	836	$\alpha-PbSO_4$
23	71	848	
24	72	860	
25	73	868	
26	74	890	$\beta-PbSO_4$
27	75	910	
28	80	980	

TABLE 7

Section III – [25% Na_2WO_4 – 75% Na_2SO_4] ⟶ $PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	794	$Na_2\|SO_4, WO_4$
2	1	800	
3	3	807	
4	5	814	
5	7	818	
6	8	819	
7	9	826	$PbWO_4$
8	10	835	
9	15	865	
10	20	884	
11	25	896	
12	30	902	
13	35	900	
14	40	895	
15	45	888	
16	50	875	
17	55	852	
18	57	839	
19	59	840	$\alpha-PbSO_4$
20	60	852	
21	61	860	
22	62	868	$\beta-PbSO_4$
23	63	882	
24	64	900	
25	65	915	
26	70	955	

TABLE 8

Section IV – [90% Na_2SO_4 – 10% Na_2WO_4] ⟶ $PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	850	$Na_2\|SO_4, WO_4$
2	5	876	
3	10	880	
4	15	876	
5	20	868	
6	25	855	
7	30	838	
8	35	825	
9	40	815	
10	45	800	
11	50	776	
12	51	766	$Na_2\|SO_4, WO_4$
13	52	748	
14	53	725	$Na_2\|SO_4, WO_4–PbSO_4$
15	54	748	$\alpha-PbSO_4$
16	55	773	
17	57	800	
18	60	834	
19	65	868	$\alpha, \beta-PbSO_4$
20	67	908	$\beta-PbSO_4$
21	70	950	
22	75	995	

TABLE 9

Section V – [50% Na_2SO_4 – 50% $PbSO_4$] $\longrightarrow$ Na_2WO_4

Expt. No.	Na_2WO_4 (%)	Temp. of appearance of first crystals	Solid phase
1	0	775	$\beta - PbSO_4$
2	1	750	
3	2	740	$\beta - PbSO_4 - Na_2 \| SO_4, WO_4$
4	3	730	$Na_2 \| SO_4, WO_4$
5	4	763	
6	5	785	
7	7	798	$Na_2 \| SO_4, WO_4 - PbWO_4$
8	8	818	$PbWO_4$
9	10	850	
10	15	895	
11	20	913	
12	25	920	
13	30	918	
14	35	910	
15	40	896	
16	45	875	
17	50	850	
18	55	820	
19	60	785	
20	65	750	
21	70	707	
22	75	663	
23	77	642	
24	80	645	
25	85	658	$Na_2 \| SO_4, WO_4$
26	90	672	
27	95	685	
28	100	695	Na_2WO_4

TABLE 10

Section VI – [60% $PbSO_4$ – 40% Na_2SO_4] $\longrightarrow$ Na_2WO_4

Expt. No.	Na_2WO_4 (%)	Temp. of appearance of first crystals	Solid phase
1	0	816	$PbSO_4$
2	4	803	
3	5	799	
4	7	792	
5	8	816	$PbWO_4$
6	10	848	
7	15	884	
8	20	905	
9	25	916	
10	30	924	
11	35	925	
12	40	915	
13	45	900	
14	50	875	
15	55	846	
16	60	815	
17	65	780	
18	70	745	
19	75	690	
20	78	650	
21	80	630	$PbWO_4 - Na_2 \| SO_4, WO_4$
22	83	638	$Na_2 \| SO_4, WO_4$
23	85	644	
24	90	660	
25	95	676	
26	100	695	

TABLE 11

Section VII – [90% Na_2WO_4 – 10% $PbWO_4$] $\longrightarrow$ Na_2SO_4

Expt. No.	Na_2SO_4	Temp. of appearance of first crystals	Solid phase
1	0	647	$Na_2 \| SO_4, WO_4$
2	5	638	
3	10	636	
4	15	643	
5	20	650	
6	25	657	
7	30	666	
8	35	675	
9	40	684	
10	45	692	
11	50	715	$Na_2 \| SO_4, WO_4$
12	55	730	
13	60	748	
14	65	770	
15	70	789	
16	75	812	
17	80	830	
18	85	850	
19	90	868	
20	100	884	Na_2SO_4

TABLE 12

Section VIII – [75% Na_2SO_4 – 25% $PbSO_4$] ⟶ Na_2WO_4

Expt. No.	Na_2WO_4 (%)	Temp. of appearance of first crystals	Solid phase
1	0	865	Na_2SO_4
2	5	862	$Na_2 \| SO_4, WO_4$
3	10	859	
4	13	870	$PbWO_4$
5	15	875	
6	20	880	
7	25	878	
8	30	870	
9	35	850	
10	40	824	
11	45	785	
12	50	753	
13	55	724	
14	60	695	
15	65	670	
16	70	666	
17	75	670	$Na_2 \| SO_4, WO_4$
18	80	674	
19	85	680	
20	90	685	
21	95	690	
22	100	695	Na_2WO_4

TABLE 14

Section X – [85 % $PbSO_4$ – 15% $PbWO_4$] ⟶ Na_2WO_4

Expt. No.	Na_2WO_4	Temp. of appearance of first crystals	Solid phase
1	10	964	$PbSO_4$
2	11	944	
3	12	916	
4	13	904	
5	15	892	
6	20	920	$PbWO_4$
7	25	944	
8	30	958	
9	35	965	
10	40	964	
11	45	960	
12	50	945	

TABLE 13

Section IX – [25% Na_2SO_4 – 75% $PbSO_4$] ⟶ Na_2WO_4

Expt.	Na_2WO_4	Temp. of appearance of first crystals	Solid phase
1	0	–	
2	5	960	β – $PbSO_4$
3	8	930	
4	9	914	
5	10	895	
6	11	868	β–$PbSO_4$, α–$PbSO_4$
7	12	860	α–$PbSO_4$
8	13	844	
9	14	834	$PbWO_4$
10	15	846	
11	17	868	
12	20	890	
13	25	912	
14	30	929	
15	35	932	
16	40	930	
17	45	915	
18	50	898	
19	55	876	
20	60	848	
21	65	810	
22	70	760	
23	75	710	
24	80	645	
25	85	634	
26	90	650	$Na_2 \| SO_4, WO_4$
27	95	672	
28	100	695	Na_2WO_4

TABLE 15

Section XI – [15% $PbWO_4$ – 85% Na_2WO_4] ⟶ $PbSO_4$

Expt. No.	$PbSO_4$ (%)	Temp. of appearance of first crystals	Solid phase
1	0	625	Na_2WO_4
2	1	620	$Na_2 \| SO_4, WO_4$
3	3	612	
4	5	615	$PbWO_4$
5	7	638	
6	10	675	
7	15	725	
8	20	775	
9	25	824	
10	30	868	
11	35	907	
12	40	944	

TABLE 16

No. of fields	Field of crystallization	Area (in % of total area of square)	
	Solid solution		
I	$Na_2 \| SO_4, WO_4$	13.5	
II	$PbWO_4$	75.6	
III	$\beta-PbSO_4$	1.8	10.9
IV	$\alpha-PbSO_4$	9.1	

The diagonal section of Na_2WO_4–$PbSO_4$ (Table 3, Fig.1, III) intersects three cyrstallization fields; the liquidus line correspondingly consists of three branches: the $NaWO_4$ branch, intersecting the $PbWO_4$ crystallization branch at 617° and 14 % $PbSO_4$; and the $PbSO_4$ crystallization branch, intersecting the $PbWO_4$ branch at 860° and 78.5% $PbSO_4$.

The diagonal section of Na_2SO_4–$PbWO_4$ (Table 4, Figure 1,I) has the character of a binary system with a simple eutectic at 860° and 15% $PbWO_4$. The liquidus line has a small sloping portion between 30 and 40% $PbWO_4$.

Section I – [75% $NaWO_4$–25% Na_2SO_4] ⟶ $PbSO_4$ (Table 5, Figure 3) passes through 3 crystallization fields: The solid solutions $Na_2 \| SO_4, WO_4$; lead tungstate and lead sulfate. Eutectic points are: $Na_2 \| SO_4, WO_4$–$PbWO_4$ at 660° and 9% $PbSO_4$; $PbSO_4$–$PbWO_4$ at 836° and 75% $PbSO_4$. A polymorphic transformation occurs at 868° on the $PbSO_4$ crystallization branch.

Section II – [50% Na_2WO_4–50% Na_2SO_4]→$PbSO_4$ (Table 6, Fig 3)–resembles the first section. Eutectic points are: $Na_2 \| SO_4, WO_4$–$PbWO_4$, at 708° and 7% $PbSO_4$; $PbWO_4$–$PbSO_4$, at 830° and 69.9% $PbSO_4$. Polymorphic transformation of $PbSO_4$ at 868°.

Section III – [25% Na_2WO_4–75% Na_2SO_4]→$PbSO_4$ (Table 7,Fig.3). –is similar to sections I and II. Eutectic points are: $Na_2 \| SO_4, WO_4$–$PbWO_4$

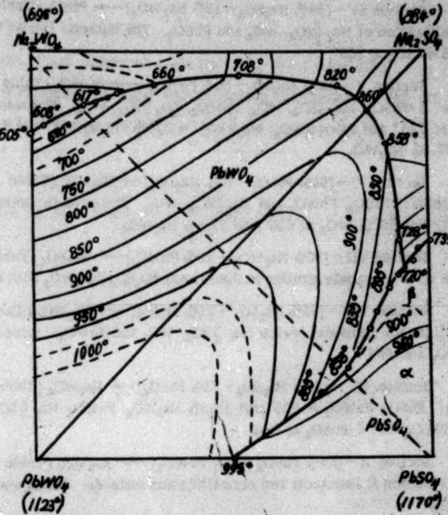

Fig. 5. Projection of the 3-dimensional diagram on to the square of compositions of the reciprocal system.

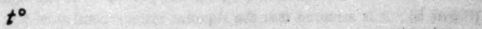

Fig. 6. Projections of the eutectic lines. A) on to the Na_2WO_4–$PbWO_4$ side; B) on to the $PbWO_4$–$PbSO_4$ side.

at 820° and 8.5% $PbSO_4$; $PbWO_4$–$PbSO_4$ at 825° and 58% $PbSO_4$. Transition from the α- to the β-modification of $PbSO_4$ at 868°.

Section IV – [90% Na_2SO_4 – 10% Na_2WO_4] $\longrightarrow$ $PbSO_4$ (Table 8, Fig.3) – only passes through 2 fields of crystallization of $Na_2 \| SO_4, WO_4$ and $PbSO_4$. The eutectic lies at 725° and 53% $PbSO_4$. Transition of α-$PbSO_4$ into β-$PbSO_4$ at 868°.

Section V – [50% Na_2SO_4 – 50% $PbSO_4$] $\longrightarrow$ Na_2WO_4 (Table 9, Figure 4) – intersects 4 crystallization fields: β-$PbSO_4$, $Na_2 \| SO_4, WO_4$, $PbWO_4$, $Na_2 \| SO_4, WO_4$. The respective eutectic points are: β-$PbSO_4$–$Na_2 \| SO_4, WO_4$ at 730° and 3% Na_2WO_4; $Na_2 \| SO_4, WO_4$–$PbWO_4$ at 798° and 7% Na_2WO_4; and $PbWO_4$–$Na_2 \| SO_4, WO_4$ at 637° and 77.5% Na_2WO_4.

Section VI – [60% $PbSO_4$ – 40% Na_2SO_4] $\longrightarrow$ Na_2WO_4 (Table 10, Fig.4) – intersects the following crystallization fields: $PbSO_4$, $PbWO_4$ and $Na_2 \| SO_4, WO_4$. The eutectic points are: $PbSO_4$–$PbWO_4$ at 789° and 7.5% Na_2WO_4; $PbWO_4$–$Na_2 \| SO_4, WO_4$ at 630° and 79.5% Na_2WO_4.

Section VII – [90% Na_2WO_4 – 10% $PbWO_4$] $\longrightarrow$ Na_2SO_4 (Table 11, Fig.4) – is a control section; as seen on Figure 4, it is entirely similar to the system Na_2SO_4–Na_2WO_4 with a minimum at 636°.

Section VIII – [75% Na_2SO_4 – 25% $PbSO_4$] $\longrightarrow$ Na_2WO_4 (Table 12, Fig. 4) – intersects the fields of the crystallization surfaces: twice $Na_2 \| SO_4, WO_4$ and $PbWO_4$. Eutectics: At 10% Na_2WO_4 and 858°, and at 67% Na_2WO_4 and 664°.

Section IX – [25% Na_2SO_4 – 75% $PbSO_4$] $\longrightarrow$ Na_2WO_4 (Table 13, Fig. 4) – resembles section VI. Eutectic points: $PbSO_4$–$PbWO_4$ at 825° and 13.5% Na_2WO_4; $PbWO_4$–$Na_2 \| SO_4, WO_4$ at 622° and 81.5% $NaWO_4$. Transition of α-$PbSO_4$ into β-$PbSO_4$ at 868°.

Section X – [85% $PbSO_4$ – 15% $PbWO_4$] $\longrightarrow$ Na_2WO_4 (Table 14, Fig.4) – was investigated to 50% Na_2WO_4; on this portion it intersects two crystallization surfaces: $PbSO_4$ and $PbWO_4$. The eutectic lies at 885° and 14% Na_2WO_4.

Section XI – [15% $PbWO_4$ – 85% Na_2WO_4] $\longrightarrow$ $PbSO_4$ (Table 15, Fig.4) – was investigated to 40% $PbSO_4$; in this range it intersects two crystallization suffaces. The eutectic is at 608° and 4% $PbSO_4$.

On the basis of the data for the fusibility of the binary systems (sides of the square) diagonal sections and internal sections, a projection diagram was plotted on to the square of compositions of the reciprocal system (Figure 5). It is assumed that the liquidus surface consists of four crystallization fields: The solid solutions $Na_2 \| SO_4, WO_4$, $PbWO_4$, α- and β-$PbSO_4$. The corresponding areas of the crystallization fields are presented in Table 16.

The projections of the eutectics on the sides Na_2WO_4–$PbWO_4$ and $PbWO_4$–$PbSO_4$ (Figure 6) meet in a ternary eutectic point at 720° and the composition: 48.5% $PbSO_4$, 5.5% $PbWO_4$ and 46% Na_2SO_4. The diagonal section Na_2SO_4–$PbWO_4$ has the character of a binary system with a simple eutectic. The eutectic point lies at 860° and 15% $PbWO_4$ (Figure 5) and is the saddle point of the reciprocal system.

Due to the lack of data for the heats of formation of lead and sodium tungstates, it is impossible to calculate the thermal effect of the double decomposition; it is clear, however, from the character of the diagram that the equilibrium is sharply shifted in the direction of formation of lead tungstate and sodium sulfate, i.e. in the direction of combination of ions with similar radii (Beketov [3], Gustavson [4]).

According to the classification of A. G. Bergman and N. S. Dombrovskaya [5], the system is an irreversible-reciprocal one with the stable diagonal Na_2SO_4–$PbWO_4$, although the displacement of the crest in the crystallization field of $PbWO_4$ in the direction of $PbSO_4$ points to a certain degree of reversibility of the reaction.

SUMMARY

1. A study was made by the visual-polythermal method of the liquidus surface of the reciprocal system, $Na, Pb \| SO_4, WO_4$.

2. The system is a simple irreversible-reciprocal one with the stable diagonal Na_2SO_4–$PbWO_4$.

3. The liquidus surface of the system comprises four fields of crystallization: The solid solutions $Na_2 \| SO_4, WO_4$, $PbWO_4$, α- and β-$PbSO_4$.

4. The system is characterized by one ternary eutectic at 720° and the composition: 48.5%, $PbSO_4$, 5.5% $PbWO_4$, 46% Na_2SO_4; and by one saddle point at 860°, 15% $PbWO_4$ and 85% Na_2SO_4.

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EFFECT OF TEMPERATURE ON THE REDUCTION OF ORGANIC COMPOUNDS AT THE DROPPING MERCURY ELECTRODE

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In the practice of polarographic analysis it is known that the magnitude of the diffusion current largely depends on the operating temperature. The effect of the temperature on the diffusion current may be represented by Ilkovic's equation:

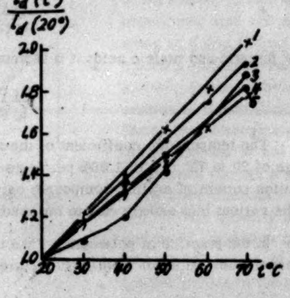
$$i_d = 605\, n\, D^{1/2} m^{2/3} t^{1/6} C, \tag{1}$$

where i_d is the diffusion current in μA); $\underline{n}$ is the number of electrons participating in the reduction of one molecule; $\underline{D}$ is the diffusion coefficient of the molecules undergoing reduction (in $cm^2 \cdot sec^{-1}$); $\underline{m}$ is the weight of mercury flowing from the capillary per second (in mg); $\underline{t}$ is the period of formation (in seconds) of each drop of mercury; $\underline{C}$ is the concentration of reacting substance (in mmole/liter).

Starting from the above expression Kolthof and Lingane [1] obtained the following expression for the temperature coefficient of the diffusion current of the ions undergoing reduction (for temperatures around 25°C):

$$\frac{1}{i_d} \cdot \frac{di_d}{dT} = 0.0026 + \frac{1}{2\lambda_0} \cdot \frac{d\lambda_0}{dT}, \tag{2}$$

where λ_0 is the equivalent ionic conductivity at infinite dilution and for the absolute temperature T.



Influence of temperature on the reduction of organic compounds.
1) Benzaldehyde; 2) butyraldehyde; 3) phenyl trichloroacetate; 4) chloracetamide; 5) maleic and fumaric acids.

The first term on the right-hand side of the equation is much smaller than the second; consequently the temperature coefficient is mainly a function of the temperature coefficient of the equivalent conductivity of the ions being reduced. The temperature coefficients of the equivalent conductivity of the majority of ions lie within the range $0.02\text{-}0.027^{\circ -1}$ with the exception of H^+ and OH^-, whose respective values are 0.0157 and $0.018^{\circ -1}$. Hence the temperature coefficient of the diffusion current of the majority of ions must have a value within the range of 1.3-1.6% per degree and must be close to 1.05% per degree for dissociation of hydrogen ions.

The experimental values of the temperature coefficients of the diffusion current of ions of various metals for temperatures of 20 to 50° vary within the range of 1.3 to 2.3% per degree [1] and are in sufficiently good agreement with the theoretical values.

Diffusion currents of organic compounds as functions of the temperature have not been investigated.

In this paper we describe the results of a study of the effect of temperature on the polarographic reduction of benzaldehyde, butyraldehyde, chloracetamide, phenyl trichloroacetate, dibutylphthalate, maleic acid, and fumaric acid.

The investigations were performed on the M-7 visual polarograph of the Gorky Chemical Research Institute [2,3]. Prior to the plotting of the polarograms the electrolyzer containing the solution of the test substance was placed in a thermostat in which a constant temperature was maintained with the help of a toluene thermoregulator and a variable current relay. The rate of flow of the mercury from the capillary was uniform throughout the investigation at one drop per four seconds. The characteristic of the capillary utilized in the work was $m^{2/3}t^{1/6} = 0.78$

$mg^{2/3}$ $sec^{-1/2}$. All the values of diffusion current on the diagram and in the tables have been converted for a capillary with a characteristic of 1.0 $mg^{2/3}$ $sec^{-1/2}$. The current strength was measured with the help of a mirror galvanometer whose current sensitivity was $0.58 \cdot 10^{-9}$ A/mm/m. The anode was a saturated calomel cell whose potential was taken as zero. The applied voltage was measured with the help of a voltmeter accurate to 0.01 V.

The temperature dependence of the diffusion current of the investigated organic compounds is given in the diagram. The effect of temperature on the diffusion current and half-wave potential of butyraldehyde and maleic acid is shown by the experimental data presented in Tables 1 and 2.

TABLE 1
Effect of Temperature on the Reduction of Butyraldehyde in $(CH_3)_4NI$. C = 4.8 mmoles/liter

t° C	i_d μA	$\frac{i_d\,(t°)}{i_d\,(20°)}$	$-E_{1/2}$ B
20	15.3	1.00	1.88
30	18.0	1.18	1.88
40	25.5	1.67	1.88
50	29.6	1.93	1.90
60	30.0	1.96	1.88
70	30.6	2.00	1.86

TABLE 2
Effect of Temperature on the Reduction of Maleic Acid in $(CH_3)_4NI$. C = 4.0 mmoles/liter

t° C	i_d μA	$\frac{i_d\,(t°)}{i_d\,(20°)}$	$-E_{1/2}$ B
20	11.6	1.00	0.95
30	13.9	1.20	0.92
40	15.3	1.32	0.93
50	17.0	1.47	0.92
60	20.4	1.76	0.93
70	24.5	2.12	0.93

The diagram and the tables show that the temperature coefficient of all the investigated compounds with the exception of phenyl trichloroacetate remains constant with change of temperature from 20 to 70°, and that there is a straight-line dependence of the ratio of the diffusion current at a given temperature to the value at 20° on the temperature. The slope of the straight line varies for each compound investigated and varies slightly with the structure of the compound. In the case of benzaldehyde, for instance, the relation between $\frac{i_d(t°)}{i_d(20°)}$ and the temperature is represented by the formula:

$$\frac{i_d\,(t°)}{i_d\,(20°)} = 0.0021t \qquad (3)$$

while for fumaric and maleic acids it is represented by:

$$\frac{i_d\,(t°)}{i_d\,(20°)} = 0.0156t. \qquad (4)$$

The temperature coefficient of the diffusion current during reduction of organic compounds in the temperature range of 20 to 70° is 1.15-1.50% per degree. The experimental values show that the temperature coefficients of the diffusion current of organic compounds only differ slightly from the temperature coefficients of the diffusion current of the various ions and are close to the theoretical magnitude.

In the practice of polarography the temperature should be kept constant to within at least ±0.5° in order to ensure that the deviations of the diffusion current due to the temperature change should not exceed ±1.0%.

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PHYSICOCHEMICAL ANALYSIS OF THE SYSTEMS PHENOL-MONOCHLORACETIC ACID AND PHENOL-TRICHLORACETIC ACID

V. V. Udovenko, R. P. Airapetova and V. T. Malakhova

It has previously been shown [1] that the components do not react with each other in the system phenol-formic acid. It was of interest to investigate the effect of replacing formic acid by stronger acids. We, therefore, carried out an investigation, by the method of thermal analysis and of viscosity measurements, of the systems: phenol-monochloracetic acid and phenol-trichloracetic acid.

The acids were purified by recrystallization from benzene followed by distillation. The boiling point of the monochloracetic acid was 186.3° (733 mm), and that of the trichloracetic acid was 192.8° (731 mm). The phenol was purified by repeated distillation. It boiled at 180.4° (730 mm). The pure substances were stored in sealed tubes.

Thermal analysis was carried out visually as described in the previous paper [1]. The viscosity and density were measured at 50, 60 and 75°. The phase diagram of the system phenol-monochloracetic acid is represented in Figure 1. It contains only one eutectic, whose composition corresponds to 57 mole-% phenol; the melting point is 3°. We succeeded in following the crystallization of the eutectic in mixtures containing from 49 to 68.7% phenol. Kendall also reports that the phase diagram of this system contains one eutectic [3].

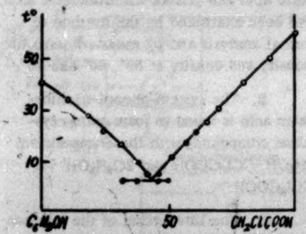

Fig. 1. Phase diagram of the system phenol-monochloracetic acid.

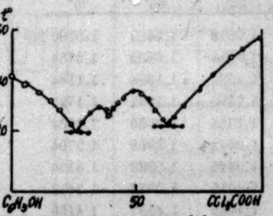

Fig. 2. Phase diagram of the system phenol-trichloracetic acid.

Results of viscosity and density measurements of the system phenol-monochloracetic acid are presented in Table 1, from which viscosity isotherms were plotted. In the high-concentration region these isotherms pass through a diffuse maximum, and at low concentrations through a very ill-defined minimum. The form of the viscosity isotherms of the system phenol-monochloracetic acid is similar to that in the system nitrobenzene-formic acid [2]. The presence of a weak maximum on the viscosity isotherms of the system phenol-monochloracetic acid testifies to reaction between the components in the liquid phase. The weakness of the reaction prevents the formation of a compound crystallizing in the solid state.

The diagram of thermal analysis of the system phenol-trichloracetic acid is shown in Figure 2. In this system the components interact chemically with formation of two crystalline compounds. The distectic maxima on the diagram correspond precisely to an equimolecular compound and to a compound containing two molecules of phenol per molecule of acid. The phase diagram also contains three eutectics. The eutectic with 73.9 mole-% phenol melts at 20°. We observed the melting point of this eutectic in the concentration range of 68.4 to 76.6 mole-% phenol. The eutectic containing 60.6 mole-% phenol melts at 26°, and that containing 37.9 mole-% phenol melts at 22°. We were able to follow the eutectic melting point of the latter in mixtures containing from 30.8 to 43.2% mole-% phenol. We repeated the thermal analysis of the system phenol-trichloracetic acid several times and each

TABLE 1

System Phenol-Monochloracetic Acid

Mole-%	Viscosity (centipoises)			Density		
Phenol	50°	60°	75°	50°	60°	75°
100	3.336	2.521	1.742	1.0499	1.0399	1.0280
90.30	3.353	2.527	1.763	1.0745	1.0638	1.0525
82.16	3.338	2.524	1.768	1.0943	1.0856	1.0736
75.67	3.308	2.508	1.771	1.1133	1.1053	1.0918
70.37	3.277	2.505	1.768	1.1300	1.1204	1.1116
67.35	3.242	2.497	1.765	1.1380	1.1307	1.1148
60.60	3.203	2.493	1.761	1.1562	1.1491	1.1324
51.13	3.142	2.441	1.762	1.1916	1.1852	1.1661
40.50	3.121	2.435	1.782	1.2212	1.2119	1.1954
30.59	3.112	2.431	1.790	1.2596	1.2500	1.2320
26.00	3.103	2.427	1.803	1.2826	1.2718	1.2548
19.18	3.113	2.428	1.809	1.3120	1.2982	1.2808
11.28	3.125	2.436	1.819	1.3327	1.3230	1.3052
0	–	2.442	1.835	–	1.3720	1.3520

time we obtained the phase diagram shown in Figure 2. Furthermore, compounds with the compositions $C_6H_5OH \cdot CCl_3COOH$ and $2C_6H_5OH \cdot CCl_3COOH$ were isolated and recrystallized from benzene. The pure compounds form white crystals melting at 37.8° and 31.2° respectively.

Thermal analysis of the system phenol-trichloracetic acid has been carried out by Kendall [3] and by Puschin and Rikovčki [4]. Their phase diagram contains only one distectic corresponding to the equimolecular compound. Kendall gives 37.6° as the melting point of the equimolecular compound. The failure of Kendall and of Puschin and Rikovcki to observe a second distectic can be explained by the fact that they only studied a comparatively small number of points.

Results of measurements of the viscosity and density of the system phenol-trichloracetic acid are presented in Table 2. The viscosity isotherms of this system have an irrational maximum which is shifted in the acid direction with rising temperature. Consequently the interaction of the components in this system is reflected both on the phase diagram and on the viscosity isotherms. In the system phenol-monochloracetic acid, however, the weaker interaction of the components is only reflected on the viscosity isotherms.

TABLE 2

System Phenol-Trichloracetic Acid

Mole-%	Viscosity (centipoises)			Density		
Phenol	50°	60°	75°	50°	60°	75°
100	3.278	2.494	1.737	1.0518	1.0427	1.0290
91.17	3.569	2.721	1.865	1.0954	1.0902	1.0754
85.44	3.811	2.900	1.977	1.1382	1.1324	1.1184
76.00	4.127	3.127	2.141	1.1990	1.1901	1.1721
69.28	4.342	3.248	2.238	1.2754	1.2030	1.2004
59.25	4.683	3.482	2.386	1.2942	1.2869	1.2704
50.25	4.779	3.666	2.513	1.3445	1.3323	1.3150
40.32	5.012	3.778	2.617	1.4015	1.3917	1.3638
33.05	5.085	3.886	2.706	1.4445	1.4337	1.4160
24.50	5.126	3.894	2.754	1.4863	1.4770	1.4586
18.34	5.115	3.878	2.792	1.5195	1.5074	1.4863
10.05	5.083	3.837	2.815	1.5667	1.5462	1.5330
0.	4.797	3.786	2.779	1.6181	1.6048	1.5776

SUMMARY

1. The systems phenol-monochloracetic acid and phenol-trichloracetic acid have been examined by the method of thermal analysis and by measurements of viscosity and density at 50°, 60° and 75°.

2. The system phenol-trichloracetic acid is found to form solid crystalline compounds with the compositions $C_6H_5OH \cdot CCl_3COOH$ and $2C_6H_5OH \cdot CCl_3COOH$.

3. The interaction of the components in the two systems is shown to be reflected in the form of the viscosity isotherms.

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THE ELECTRIC CONDUCTIVITY OF HYDROCARBON SOLUTIONS OF IODINE

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As far as we are aware the electric conductivity of hydrocarbon solutions of iodine has only received attention in the studies of Brunner and Rabinovich.

Due to the roughness of the method of measurement, Brunner [1] was unable to detect any appreciable conductivity of the iodine solutions in toluene, whereas Rabinovich [2] found that benzene solutions, up to high concentrations (16.8%), conduct current nearly twice as badly as the original benzene whose specific electric conductivity was $7.8 \cdot 10^{-13}$ reciprocal ohms /cm.

These data, especially Rabinovich's, have not been verified. It appeared uncertain that iodine could lower the electric conductivity of benzene in which, incidentally, it could not dissolve at room temperature in such high (16.8%) concentration.

In the investigation of the mechanism of corrosion of metals in hydrocarbon solutions of iodine [3-5] we had to know the specific electric conductivity of such solutions and its dependence on the potential of the electric field. This also prompted us to carry out the determinations.

EXPERIMENTAL

We investigated the specific electric conductivity of isooctane and benzene solutions of iodine.

The isooctane [d_4^{20}–0.700; b. p. (765 mm) 97-99°] and benzene [d_4^{20}–0.874; b.p. (765 mm) 80.5°] were thoroughly dried over sodium.

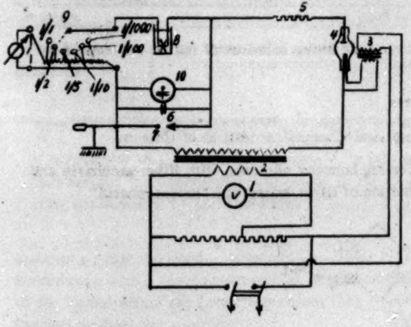


Figure 1. High-voltage apparatus.
1 - Guard voltmeter; 2 - step-up transformer; 3 - heat transformer; 4 - VCh-2000 thermionic rectifier; 5 - 30,000 ohms resistance; 6 - two microfarads condenser; 7 - discharger; 8 - cell for determination of electric conductivity; 9 - Ayrton shunt and 10^{-9} A galvanometer; 10 - static voltmeter.

The iodine (chemically pure) was twice sublimed over KI and BaO, after which it was again sublimed and dried over P_2O_5.

The high-voltage apparatus used by us in the measurements is sketched in Fig. 1. This apparatus permitted the application to the electrodes of potentials of 300 to 4000 V and the attainment of an electric field potential of 40,000 V/cm. The source of current up to 300 V was a BAS-80 battery.

Currents were measured with a mirror galvanometer with a scale division equivalent to $1.53 \cdot 10^{-9}$ A.

The glass conductivity cell was provided with Rogovsky platinum electrodes, fixed parallel to each other and 1 mm apart; their inner working surface was polished.

The vessel containing the test liquid was placed in a "thermostat-desiccator" which consisted of a Plexiglass housing, , heated by an electric lamp turned upside down, containing sulfuric acid, phosphorus pentoxide and other desiccants. This simple device ensured constancy of temperature and, what is particularly important, provided protection against current leakages due to condensation of water on the walls of the vessel.

After distilling the hydrocarbon into the cell and determining its specific conductivity, the weighed amount of iodine was dissolved in it (when the conductivity had been found minimal). The volt-ampere characteristic of the solution was then plotted. The conductivity of a 0.0078 N solution was measured; the low dilution was due to the poor solubility of iodine in isooctane. The volt-ampere characteristic was plotted for at least three freshly prepared solutions, and the results were only considered reliable when they substantially agreed with one another. Measurements were performed at 20°.

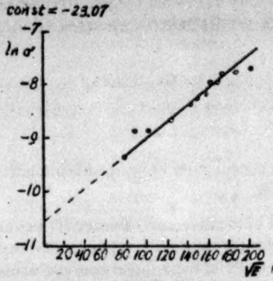


Fig. 2. Electric conductivity of isooctane solutions of iodine

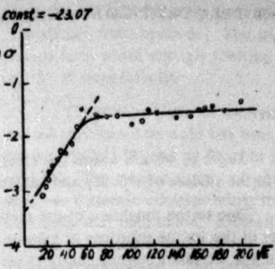


Fig. 3. Electric conductivity of benzene solutions of iodine

Evaluation of Results

The first feature which stands out is that not only is the conductivity of the benzene solution very much better than that of the original benzene (in opposition to Rabinovich's observation), but it is slightly better than that of the isooctane solution. The specific electric conductivity (σ) at E = 7500 V/cm of 0.0078 N benzene solution of iodine is $1.27 \cdot 10^{-11}$ reciprocal ohm/cm^{-1}(the σ of pure benzene is $1.28 \cdot 10^{-14}$), whereas the σ of 0.0078 N isooctane solution of iodine is $8.57 \cdot 10^{-13}$ (the σ of pure isooctane is slightly lower).

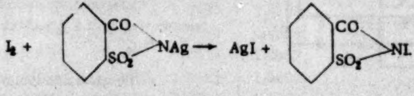
Isooctane and benzene solutions of iodine are respectively violet and brown. Hildebrand [6] draws a sharp distinction between them. He regards the violet solutions as regular solutions which "resemble ideal solutions in the sense that the thermal motion of their molecules is able to overcome the orienting tendency of the molecules, their combination or association and to bring about the completely disordered distribution existing in ideal solutions", i.e. in solutions obeying Raoult's law. But the brown or, more correctly, the gamut of red, yellow and brown solutions he regards as irregular solutions deviating from Raoult's law by virtue of the inherent tendency of their molecules to associate and solvate. In fact a series of investigators has correlated the solvation of iodine in the brown solutions with the electrolytic dissociation therein of the I_2 molecules.

Walden [7,8] was the first to suggest that the conductivity of the brown solutions of iodine was caused by dissociation according to the scheme:

(1) $I_2 \rightleftharpoons I^+ + I^-$ and (2) $2I_2 \rightleftharpoons 3I^- + I^{+++}$.

This concept of Walden's found support in the work of Feigl and Chargaff, as well as of Ushakov.

Feigl and Chargaff [9] treated the brown solutions, including benzene solutions, with silver saccharin and observed that a double decomposition readily took place with formation of silver iodine and "iodosaccharin".



Ushakov [10] treated alcoholic (brown) solutions of iodine with silver nitrate and established the formation of not only silver iodide but also of the nitrates of mono- and trivalent iodine; in other words he demonstrated, so to speak, the occurrence in these solutions of the following reactions:

1) $I_2 + 2AgNO_3 \rightleftharpoons INO_3 + AgI \cdot AgNO_3$;

2) $2I_2 + 6AgNO_3 \rightleftharpoons I(NO_3)_3 + 3AgI \cdot AgNO_3$.

These results led Ushakov to conclude that the iodine was dissociated in the investigated solutions in accordance with Walden's scheme; the mono- and trivalent iodine cations are linked by the equilibrium:

$$3I^+ \rightleftharpoons I^{+++} + I_2.$$

Fialkov [11] also adheres to the view that iodine is susceptible to electrolytic dissociation in solutions, especially in those where complex-formation takes place.

All these investigators had in mind the dissociation of iodine in brown solutions and were not concerned at all with the violet ones. The reaction of Feigl and Chargaff with silver saccharin proceeded much less readily in the violet solutions, in particular in petroleum ether (the closest in character to isooctane), than in the brown solutions.

In the light of the above facts the observed better conductivity of the brown benzene solutions (compared with the violet isooctane solutions) can be regarded as the consequence of the slightly higher dissociation of iodine in the former.

However, we must point out that even though this interpretation appears to be well-founded, another explanation is possible. If we assume, namely, that in the above-described conditions iodination of the hydrocarbons takes place, then we could put forward an entirely different mechanism of the conductivity of these solutions which involves the reactions:

$$1)\ RH + I_2 \rightleftharpoons RI + HI;$$

$$2)\ HI \rightleftharpoons H^+ + I^- .$$

According to this mechanism electric conductivity is the consequence of dissociation of hydrogen iodide and not of molecular iodine. The superior conductivity of benzene solutions of iodine compared with the isooctane ones can then be explained by the greater ease of iodination of benzene in comparison with that of isooctane. Such a theory is intriguing in its simplicity, for the electrolytic dissociation of hydrogen iodine seems much more probable than that of molecular iodine. Concerning the data of Feigl and Chargaff and of Ushakov, it may be suggested that they were affected by the quality of the reagents.

Comparing the number of molecules of iodine in 1 ml of the solutions in question ($4.7 \cdot 10^{18}$) with their maximum content of ions ($2.0 \cdot 10^{11}$) (see table), we can easily realize that a negligible proportion ($0.4 \cdot 10^{-7}$) of the I_2 molecules gives rise to ions. Such a number could, of course, have been formed by dissociation of either I_2 or HI. A second, most interesting feature of the data is the exponential increase in the conductivity of the solutions with increasing field potential.

As is known, Poole [13] gave the formula: $\sigma = \sigma_0 e^{\alpha E}$, (where α is a constant), according to which the logarithm of conductivity of solid dielectrics (mica) are directly proportional to the field potential. As further investigations showed, however, Poole's formula does not fully describe the behavior of dielectrics in strong fields.

Number of Ions (n') in Iodine Solutions at Various Field Potentials.

Solution	$E \rightarrow 0$	E = 3400 V/cm	E = 40,000 V/cm
Isooctane	$4.63 \cdot 10^7$	–	$3.36 \cdot 10^8$
Benzene	$2.81 \cdot 10^{10}$	$1.60 \cdot 10^{11}$	$2.00 \cdot 10^{11}$

Note: $n' = \frac{\sigma}{e \cdot w}$; $e = 1.6 \cdot 10^{-19}$ coulomb; $w = 6.9 \cdot 10^{-4}$ cm²/sec. V = mobility of I^- in aqueous solutions[*]. It follows from the Avogadro number and the concentration of iodine in the solutions that one milliliter contained $4.7 \cdot 10^{18}$ molecules of I_2.

It is described more correctly by Frenkel's equation [14]. On the assumption that the conductivity of electrolytes in strong electric fields is due to the fall of ionization energy in accordance with a mechanism similar to the Schottke mechanism, i.e., that the ionization occurs not as a result of the tunnel effect (as Zener suggestions [15], as well as other authors) but of the classical "thermal" effect, Frenkel derived the equation:

$$\sigma = \sigma_0 e^{\frac{\sqrt{e^3E/\epsilon}}{kT}} .$$

It follows from this equation that direct dependence must exist between the logarithm of the conductivity and the square root of the field potential. Frenkel, also Poole, had electronic conductivity in mind. In actuality, however, his equation is also applicable to dielectrics with ionic conductivity, such as the solutions under investigation. Evidently their ionization energy, under the influence of the electric field, is also reduced by the amount $\sqrt{e^3E/\epsilon}$ (where $\underline{e}$ is the electronic charge, $\underline{E}$ is the field potential and ϵ is the dielectric permeability). On applying this equation to the interpretation of the experimental data we did indeed find a linear dependence of ln σ on $\sqrt{E}$ in the case of the isooctane solution of iodine (Fig. 2).

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[*] The mobility of certain ions, in hexane for instance, differs slightly, according to the literature, from their mobility in aqueous solutions [12]. We have replaced the sum of the ionic mobilities in the formula $\sigma = en(w_+ + w_-)$ by the mobility of one ion, which is not of great significance, since we are only interested in the order of magnitude of n'.

Analogous measurements were carried out in 1943 by Chia Chan Pao [16] who investigated the behavior of I in the strong fields of isooctane and liquid oxygen. He obtained the same linear relation (in plots of ln σ against $\sqrt{E}$) as we did. We obtained a value of 0.27 for the tangent of the slope of the straight line in Figure 2 for the isooctane solution of iodine (using absolute units), whereas the angular coefficients of the straight lines for isooctane obtained by Chia Chan Pao were 2.5 times as large (after converting from base 10 logarithms to natural logarithms).

It should be noted that the theoretical value of this tangent is $\frac{\sqrt{e^3/\epsilon}}{kT}$. At room temperature and when $\epsilon = 1$, it is equal to 0.28, i.e., very close to our measurement on the assumption that $\epsilon = 1$. Actually, however, the dielectric permeability of a solution of iodine in isooctane must be slightly larger (approximately 2-3).

If this fact is taken into account the agreement between theory and our experimental results becomes rather worse, and the deviation is greater in the case of Pao's results. The reason for these divergencies will be considered elsewhere.

In the case of the benzene solution the dependence of ln σ on $\sqrt{E}$ had a very singular character. The graph representing this dependence (Fig. 3) consists of two intersecting straight lines. In the range of values of $\underline{E}$ from 0 to 3400 V/cm, Frenkel's relation remains valid and is reflected in a straight line with an angle of slope whose tangent is 0.46. On passing this limit in the value of $\underline{E}$, however, the straight line abruptly changes direction and its angular coefficient becomes so small that σ ceases to increase with further intensification of the electric field. This turning point is evidently due to electrolytic (high-potential) polarization of the dielectric, since in the present case with a field potential greater than 3400 V/cm, we must regard $\underline{E}$ not as the applied field but as the effective field, equal to $\frac{V-P}{d}$, where $\underline{V}$ is the imposed voltage, $\underline{P}$ is the e.m.f. of polarization and $\underline{d}$ is the distance between the electrodes.

SUMMARY

1. The electric conductivity of 0.0078 N solutions of iodine in isooctane and benzene was investigated at electric field potentials ranging from 300 to 40,000 V/cm.

2. Solutions of iodine in isooctane and benzene conduct current better than the original hydrocarbons. The conductivity of the benzene solutions is higher than that of the isooctane solutions. The specific electric conductivity (σ) at $E = 7500$ V/cm of 0.0078 N benzene solution of iodine is $1.27 \cdot 10^{-11}$ ohm^{-1} cm^{-1}, whereas the σ of the original benzene is $1.28 \cdot 10^{-14}$ ohm^{-1} cm^{-1}; the σ of 0.0078 N solution of iodine in isooctane = $8.57 \cdot 10^{-15}$ ohm^{-1} cm^{-1}, whereas the σ of the original isooctane is less than $8.57 \cdot 10^{-15}$ ohm^{-1} cm^{-1}.

3. The electric conductivity of solutions of iodine in isooctane and benzene increases exponentially with rising electric field potential in accordance with Frenkel's equation which finds its graphical expression in the linear dependence of log σ on $\sqrt{E}$.

In conclusion it is our pleasant duty to acknowledge the valuable advice of Corresponding Member of the Academy of Sciences of the U.S.S.R. Ya. I. Frenkel and also to thank O. A. Shpanskaya for assistance in the experimental work.

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* See Consultants Bureau translation, p. 1157.

** See Consultants Bureau translation, p.1301.

THE ELECTRIC CONDUCTIVITY OF HYDROCARBON SOLUTIONS OF SATURATED FATTY ACIDS

L. G. Gindin and V. A. Kazakova

Very little has appeared in the literature about the electric conductivity of hydrocarbon solutions of carboxylic acids.

Brühl and Schröder [1], in the course of a study of the properties of camphanic acid, report that a 3.29 % benzene solution of the acid and its Na salt "do not exhibit appreciable conductivity".

Matthews [2] found a value of $3 \cdot 10^{-8}$ ohm^{-1} cm^{-1} for the specific electric conductivity of a solution of trichloracetic acid (concentration not stated) in benzene, and for this reason he described the solution as "an excellent insulator."

Rabinovich [3] studied the conductivity of some pure dielectrics and of their nonaqueous solutions and determined inter alia the specific electric conductivity (σ) of benzene solutions (σ of the benzene $\leqslant 7.8 \cdot 10^{-13}$) of palmitic and stearic acids. He found a value at 25° C of $\leqslant 3.7 \cdot 10^{-13}$ for the solutions of both acids at all concentrations up to saturation, i.e., the solutions of these acids conducted electricity twice as badly as the original benzene.

Gokhberg and Glikman [4] in an investigation of the dielectric properties of kerosene attempted to clarify the effect of the acid value on these properties. They acidified kerosene with acetic acid, dehydrated it with calcium chloride and then determined the volt-ampere characteristic of the solutions. According to their data only an increase of acid value to 2000-3000 mg KOH/100 g led to appreciable fall of the specific resistance of kerosene, whereas an increase in acidity to about 500 had little effect.

These authors were evidently dealing with inadequately dehydrated solutions, since efficient removal of water cannot be effected with calcium chloride.

This was all the scanty material available on the problem. However, we became particularly interested in obtaining further information on the subject because in our studies of the mechanism of corrosion of metals in dielectrics, especially in hydrocarbon solutions of fatty acids [5-9], we lacked the necessary data for the electric conductivity of such solutions and its dependence on the electric field potential.

In these circumstances we decided to determine the required data.

EXPERIMENTAL

We measured the electric conductivity of isooctane solutions of the first five normal members of the homologous series of fatty acids: Acetic, propionic, butyric, valeric and caproic acids, these being the main objects of our corrosion researches.

The isooctane had d_4^{20} 0.700; b.p. (765 mm) 97-99°.

The constants of the acids are listed in the table.

The conductivity was measured at 20° C in the same apparatus and by the same method as for measurements of the electric conductivity of iodine solutions [10]. Isooctane which had been thoroughly dried over sodium was distilled into the apparatus and tested for nonconductivity. The amount of acid required to form a 0.5 N solution was then dissolved in it, after which the volt-ampere characteristic of the solution was determined. A few milliliters of the solution were then used for accurate determination of the acidity, after which more acid was added to raise the concentration to 0.1 N. The volt-ampere characteristic of this solution was then determined, the concentration was again increased, and the procedure was repeated until the concentration was 1.5 N. After completing the

Constants of the Investigated Fatty Acids

Acid	d_4^{20}	Temperature of boiling at 750 mm Hg (°C)	Temperature of boiling at 28 mm Hg(°C)	Temperature of solidification (°C)	Temperature of melting (°C)	Note
Acetic	1.04926	116.0	–	16.85	–	The butyric acid was chemically pure; the remaining acids were of "limited purity" and specially prepared by IREA.
Propionic	0.99340	141.0	–	-21.7	-21.7	
Butyric	0.9640	161.8	–	–	–	
Valeric	0.93906	186.3	–	- 33.8	-33.8	
Caproic	0.92715	205.0	119.5	- 3.8	- 3.8	

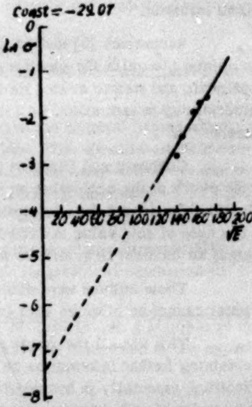
conductivity measurements on one series of solutions, we repeated the operations with a second and third series, and only when the results of measurements in all the three series coincided did they inspire us with confidence in their accuracy.*

Judging by the results of the measurements, isooctane and 0.05-1.5 N solutions therein of caproic, valeric butyric and propionic acids are distinguished by such a low conductivity that it could not be determined with our galvanometer at field potentials of 30 kV/cm. It follows, therefore, that the specific electric conductivity(σ) of the solutions in question is:

$$\leq 2.14 \cdot 10^{-15} \text{ ohm}^{-1} \text{ cm}^{-1}.$$

The same can be said about 0.05-1.0 N solutions of acetic acid. Concerning the 1.7 N solution of this acid, it exhibited insignificant conductivity in strong fields (at E = 30 kV/cm the value of σ was $3.32 \cdot 10^{-4}$ ohm^{-1} cm^{-1}). This conductivity would probably rise with increasing concentration of solution since the specific electric conductivity of acetic acid itself, according to Rabinovich [3], is a little higher than that of isooctane, namely, $1.12 \cdot 10^{-8}$. In this connection it is highly significant that with increasing electric field strength the conductivity of this solution increases exponentially in accordance with the Frenkel relation [11]:

$$\sigma = \sigma_0 e^{\frac{\sqrt{e^3 E/\epsilon}}{kT}}.$$



Electric conductivity of 1.7 N solution of acetic acid in isooctane.

SUMMARY

1. 0.05-1.0 N isooctane solutions of acetic acid and 0.05-1.5 N solutions of propionic, butyric, valeric and caproic acids are dielectrics. Their specific electric conductivity σ (at E = 30 kV/cm) $\leq 2.14 \cdot 10^{-15}$ ohm^{-1} cm^{-1}.

2. The σ of 1.7 N acetic acid in isooctane (at E = 30 kV/cm) is $3.32 \cdot 10^{-14}$ ohm^{-1} cm^{-1}. This solution exhibits exponential increase in conductivity with increasing field strength in conformity with Frenkel's equation.

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* After the measurements, the solutions were utilized in corrosion tests.

** See Consultants Bureau English translation, p. 1089.

*** See Consultants Bureau English translation, p. 1806.

OXIDATION OF HYDROCARBON BY ATMOSPHERIC OXYGEN UNDER THE INITIATING ACTION OF CHLORINE

N. I. Zemlyansky, O. A. Prib, and M. Ya. Sharypkina

There is a considerable literature on the theory and practice of oxidation of paraffin hydrocarbons with oxygen of the air, with pure oxygen and with ozone in various conditions with the aim of investigating the possibility of obtaining valuable oxygen-containing intermediate products of oxidation [1]. The formation of oxygen-containing compounds is explained by the well-known theories of Bone [2], Bakh-Engler [3] and N. N. Semenov [4]. In subsequent investigations these theories were analyzed and made more precise, [5] and none of them have been refuted. According to Semenov's theory, oxidation of paraffins involves a chain mechanism [6], and this concept was elaborated by Neiman in the sense that he regarded chain development as being largely dependent upon the free radicals which are formed in the oxidation process [7]. Several workers simultaneously established that the reaction of paraffin hydrocarbons with chlorine involves a chain mechanism [8] and may proceed according to two schemes:

$$\text{Cl}_2 \rightarrow 2\text{Cl};$$

$$\text{(I)}\quad \begin{array}{l} \text{R–H} + \text{Cl} \rightarrow \text{R} + \text{HCl}; \\ \text{R} + \text{Cl}_2 \rightarrow \text{RCl} + \text{Cl}. \end{array} \qquad \text{(II)}\quad \begin{array}{l} \text{R–H} + \text{Cl} \rightarrow \text{R–Cl} + \text{H}; \\ \text{H} + \text{Cl}_2 \rightarrow \text{HCl} + \text{Cl}. \end{array}$$

It has not up to now been established which mechanism actually applies [9]. One of us obtained data in support of the scheme involving formation of free radicals [10]. If we assume that the interaction of paraffins with chlorine proceeds via free radicals, then chlorine mixed with oxygen must assist the process of hydrocarbon oxidation.

As far back as 1931 it was experimentally established [8] that traces of oxygen inhibit the chlorination of paraffins by forming a chain [11]. There are likewise two possible mechanisms of chain-breaking:

$$\text{(I)}\ \text{R} + \text{O} \rightarrow \text{RO}; \qquad \text{(II)}\ \text{H} + \text{O} \rightarrow \text{HO}.$$

If scheme (I) above for paraffin chlorination is accepted, then chain-breaking will proceed by the first mechanism. With an insufficiency of chlorine and a large excess of oxygen, the chlorine might be expected to function as an initiator of free radical formation and thus facilitate the commencement of oxidation of paraffins by oxygen.

Consequently the initiating action of chlorine on the process of thermal oxidation of paraffins is only possible under the conditions of the first of the above chain-breaking schemes and the first of the above chlorination schemes.

We carried out experiments on the oxidation of methane with atmospheric oxygen in presence of chlorine, using various ratios of reagents and various temperature ranges. The experiments showed that in presence of chlorine the oxidation proceeds at much lower temperatures than in the absence of chlorine. In presence of chlorine the reaction products were found to include formaldehyde, formic acid, CO_2 and hydrogen chloride. In preliminary experiments on oxidation of methane with oxygen in presence of chlorine at normal pressure the presence of methyl alcohol was detected; this is normally formed by methane oxidation only under pressure. We are inclined to the opinion that these experimental data support the free-radical mechanism and also the chain-breaking mechanism (I). We also believe we have obtained a theoretical explanation of the catalytic action of chlorine and other halogens on the processes of oxidation of paraffin hydrocarbons previously reported in some patents. In our view the initiating action of chlorine on thermal oxidation of paraffin hydrocarbons proceeds by the following scheme:

$$\begin{array}{l} \text{CH}_4 + \text{Cl} \rightarrow \text{CH}_3 + \text{HCl}; \\ \text{CH}_3 + \text{O}_2 \rightarrow \text{CH}_3\text{–O–O}^{-}; \\ \text{CH}_3\text{–O–O}^{-} + \text{HCl} \rightarrow \text{CH}_3\text{–O–OH} + \text{Cl}; \\ \text{CH}_3\text{–O–O–H} \rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O}. \end{array}$$

EXPERIMENTAL

We used natural gas from the Dashau field in the Lvov region with the following composition: Methane 98.39%, higher homologs 0.55%, oxygen and nitrogen 0.01%. The chlorine was commercial gas in cylinders and was not analyzed. Air was introduced with a pump. Oxidation was performed in the apparatus here illustrated.

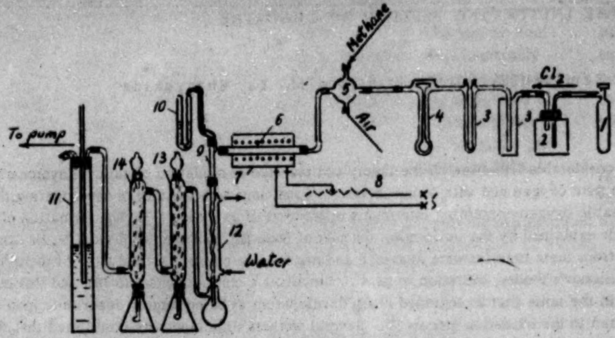

Diagram of apparatus for oxidation of methane with atmospheric oxygen in presence of chlorine.

Only the set-up for the chlorine supply is shown in the diagram since the method for feeding methane and air was the same. Gas from cylinder 1 entered the gas-purifying bottle 2. The chlorine was purified by passing through water and the methane and air were washed with 30% potassium hydroxide.

Each gas was separately dried with concentrated sulfuric acid 3 and with calcium chloride; it then passed through the flowmeter 4 and entered the glass mixer 5 whose sides were blackened. The gas mixture entered the porcelain tube 6 (diameter 1.5 cm) which was heated by the electric furnace 7. The temperature was regulated by the rheostat 8. By means of the three-way connection 9 the porcelain tube was connected with the open manometer 10 and the vertical condenser 12 to which was attached a receiver. Through a glass tube the receiver was joined to two absorption columns (in series) 13 and 14. The columns were 0.5 meter high and filled with glass rings. Distilled water trickled down the first column and standard solution of potassium hydroxide down the second. The second receiver was connected to the manostat 11 for maintenance of normal pressure in the apparatus. Withdrawal of samples of gases was effected by attaching a gasometer to the porcelain tube 6 for a definite period of time. The following components were determined in the liquid in the receivers: methyl alcohol, by formation of methyl salicylate (qualitatively); formaldehyde in the first and second receivers was determined by the method of Molotkova and Zolotukhin [12]; organic acids were determined by the difference between the total acidity, and the acidity due to hydrochloric acid (Folgard method); free chlorine was determined iodometrically; CO_2 was determined by the Winkler method [13]. A sample of the gases was analyzed in a VTI apparatus for its content of CO_2, CO, unsaturated hydrocarbons and oxygen. The amounts of methane and chlorine used in an experiment were determined. There is no information in the literature about the temperature at which methane is oxidized when passed in admixture with air through a heated tube without a catalyst. In order to determine the initiating action of chlorine on the oxidation, we carried out two experiments on oxidation of methane with oxygen of the air without chlorine by passing a methane-air mixture (ratio 1:4) at 350° and a contact time of 0.11 minute through our apparatus. The duration of the first of these experiments was 5 hours, and that of the second was 10 hours. In these conditions the methane did not react with appreciable speed with atmospheric oxygen, for even after 10 hours no products of methane oxidation could be detected. Oxidation of methane with atmospheric oxygen in presence of chlorine was performed in two series of experiments (experiments 1-5 and 6-10). The duration of each experiment was 20 hours and was conducted in two parallel apparatuses. Mean results of the experiments are presented in the table.

The data show that at a contact time of 0.11 minute methane reacts with atmospheric oxygen even at a temperature of 350°. The yield of formic acid, formaldehyde and CO_2 increases with rising temperature from 350°

Results of Oxidation of Methane with Atmospheric Oxygen in Presence of Chlorine

No. of expt.	Volume ratios methane: air: chlorine	Period of contact (minutes)	Temp.	Content of products after reaction (in %)						% of methane reacted
				Methyl alcohol	Formal-dehyde	Formic acid	CO_2	Chlorine as HCl	Free chlorine	
1	12:36:1	0.11	350°	–	0.08	0.2	0.12	16.6	30.47	0.4
2	12:36:1	0.11	500	–	0.13	0.14	0.65	54.34	None	0.92
3	12:36:1	0.11	600	–	0.16	0.94	0.68	51.87	–	1.78
4	12:36:1	0.11	800	–	0.27	1.05	1.26	94.77	–	2.58
5	12:36:1	0.04	600	–	0.36	None	0.37	41.48	15.80	0.73
6	12:37:0.006	0.22	350	–	0.059	0.16	–	33.82	57.30	0.219
7	12:37:0.006	0.22	500	–	0.054	0.16	–	72.0	26.75	0.214
8	12:37:0.006	0.22	600	–	0.065	0.14	–	94.0	None	0.205
9	12:37:0.006	0.22	800	–	0.265	0.35	–	88.1	None	0.615
10	12:37:0.006	0.13	500	–	0.058	0.14	8.09	51.35	41.62	8.20

to 800°. The increase in the formaldehyde yield is proportional to the temperature rise. Comparing the first with the second series, we see that a drop in the amount of chlorine lowers the formaldehyde yield. A fall in the duration of contact with the heated surface in the first series leads to an increased formaldehyde yield. The yield of formic acid increased in the first series with rising temperature at a contact period of 0.11, but it fell off sharply and became zero at a contact time of 0.04 minute. In the second series of experiments the yields of formic acid changed to an insignificant extent with rising temperature. Up to 600° in the first series of experiments the chlorine enters into a chlorination reaction as indicated by the amount of chlorine found as HCl. At 350° the chlorine not entering into reaction is recovered. At 800° the greater part of the chlorine is converted into hydrogen chloride which results in an increase in the yields of all the oxidation products (experiment 4). A fall in the contact time to 0.04 minute led to the appearance of unreacted chlorine (experiment 5), probably because for technical reasons we had to reduce the volume of the porcelain tube by packing with lumps of porcelain in order to reduce the time of contact. The same factor was responsible for the sharp drop in CO_2 yield in the second series with falling contact time and for the rise in the amount of unreacted chlorine.

The data justify the claim that chlorine initiates the chain reaction of oxidation of methane with atmospheric oxygen.

SUMMARY

The initiating action of chlorine on the oxidation of methane (natural gas) with atmospheric oxygen was investigated. The oxidation proceeds at lower temperatures in presence of chlorine than in its absence. Change of the contact time and of the amount of chlorine in the reaction mixture leads to change in the amount of oxidation products. Yields of formaldehyde and formic acid in presence of chlorine were much higher than in its absence in the same conditions. A reaction mechanism involving free-radical formation is confirmed by the experimental data.

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REARRANGEMENT OF HYDROGEN IN OLEFINIC HYDROCARBONS OVER ALUMINOSILICATE CATALYSTS

A. A. Petrov and A. V. Frost *

Formation of saturated hydrocarbons from olefins under the action of aluminosilicates (floridin) was first observed by S. V. Lebedev [1] in studies of the depolymerization of diisobutene and diisoamylene. Subsequently the very complex process was closely studied, although over another catalyst, by S.S. Nametkin and co-workers [2]. This process, proceeding under the action of sulfuric acid and known as "hydrodehydropolymerization", generally takes place with rearrangement of hydrogen when carried out in presence of aluminosilicates. In contrast to what happens over aluminosilicates, however, the formation of saturated products in presence of sulfuric acid is only observed in the polymer fractions. The process of hydrogen rearrangement over aluminosilicates was closely investigated by A.V. Frost and co-workers [3]. Of investigations by foreign authors we may draw attention to the work of Thomas [4] who showed that carbonaceous deposits on the catalyst play an important part in the hydrogen rearrangement.

The present investigation is mainly concerned with the dependence of hydrogen rearrangement on the structure of the original hydrocarbon. A study is also made of the effect of such factors as space velocity and amount of catalyst on the yield of saturated products. The experimental conditions excluded cracking in order, as far as possible, to obtain an accurate hydrogen balance after hydrogen rearrangement alone, and also to obtain some insight into the mechanism of the catalytic processes.

In previous researches [5] we showed that olefins with a tertiary double bond are more susceptible to saturation than olefins with a primary-secondary double bond. In this paper we report on a more comprehensive investigation of the saturation of both olefins and cycloolefins with various structures and molecular weights. Results are summarized in Table 1.

TABLE 1

Experimental Conditions: Space Velocity 0.2 1/hour; Ratio of Volumes of Catalyst and Starting Material 3:1; Duration of Experiment 100 Minutes

Initial hydrocarbon	% yield of saturated hydrocarbons	Initial hydrocarbon	% yield of saturated hydrocarbons
Hexene-1	33.7	Octene-1	38
3-Methylpentene-3	44.7	4-Methylheptene-4	51.5
2-Methylpentene-2	50.0	2-Ethylhexene-1	54.5
2,3-Dimethylbutene-2	39.5	3-Ethylhexene-2	54.6
2,2-Dimethylbutene-3	35.3	Nonene-1	62.2
Heptene-1	36.8	Nonene-4	50.6
Heptene-3	34.4	Decene-1	84.5
3-Methylhexene-2	58.4	4-Propylheptene-4	67.9
2-Methylhexene-2	62.0	5-Methylnonene-5	75
2,4-Dimethylpentene-2	41.9	Cyclohexene	99.7
5-Methylhexene-1	53.1	1-Methylcyclopentene-1	99.8

In view of the fact that the cycloolefins underwent much more saturation than the olefins, an examination of the effect of the structure of the initial cyclic hydrocarbon on the yield of saturated products was made under somewhat different conditions: Space velocity 0.6 1/hour; ratio of catalyst to raw material volume 1:1; duration of experiment 100 minutes. Results for saturation of the cycloolefins are given in Table 2.

Before discussing the data of Tables 1 and 2, we propose to consider the mechanism of the catalytic processes. The first question which presents itself is: What is the source of hydrogen for the saturation? The catalyzate from any hydrocarbon consisted of a fraction whose boiling point corresponded to isomers of the initial hydrocarbon

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* Deceased.

together with a higher boiling fraction presumably made up of polymers of the original hydrocarbon.

In none of the experiments did the monomer fraction contain products with a lower hydrogen content (aromatics, diene hydrocarbons, etc.) than in the original hydrocarbons. Consequently no reactions took place of the type of Zelinsky's irreversible catalysis on aluminosilicates and the hydrogen did not originate from the monomer fraction. The polymer fraction, especially in the experiments with olefins, had a very wide boiling range. A small proportion of aromatic hydrocarbons was found in the higher boiling portions (Table 3). This table also reveals, however, that the main constituents of the polymer fractions were the same saturated products as were found in the monomer fraction; the small aromatic content of the higher boiling fractions is most probably, as will be shown later, the result of secondary processes.

TABLE 2

Initial hydrocarbon	% yield of saturated hydrocarbons
Cyclohexene	46
1-Methylcyclohexene-1	61
1-Methylcyclohexene-3	57
1-Propylcyclohexene-1	57
Allylcyclohexene	60
1-Methylcyclopentene-1	74
1-Butylcyclopentene-1	71
Hexene-1 (for comparison)	8

Moreover the results of combustion of the polymer fractions from the experiments with hexene-1 and cyclohexene showed that these fractions yield a total of only 9% of the hydrogen required for saturation of the monomer fractions in the olefin experiments and 16% of the hydrogen needed in the cycloolefin experiments. It is thus quite clear that the main hydrogen source for saturation of olefinic hydrocarbon by hydrogen rearrangement is the formation of products of condensation over the catalyst (coke). Indeed, the formation of coke on the catalyst is in direct relation to the amount of saturated hydrocarbons formed in an experiment. On the average (from experiments with 25 different hydrocarbons) 0.45-0.52 g coke on the catalyst corresponds to each gram of saturated hydrocarbons formed. Which factors influence coke formation and, in turn, the formation of saturated hydrocarbons?

TABLE 3

Composition of Polymer Fraction of Experiments with Hexene-1 *

B.p.	Yield (in %)		n_D^{20}	% olefins	Per cent		Sulfonatable
	of starting material	of polymers			H	C	
80-100°	1.6	5.7	1.4030	68	14.55	–	–
100-150	3.1	17.8	1.4090	72	14.55	84.13	–
150-200	7.0	39.5	1.4376	65	14.19	85.06	56
200-250	3.4	19.6	1.4584	51	13.85	86.37	61
250-300	2.6	15.2	1.4916	27	12.84	87.18	74
above 300	0.3	2.0	–	–	–	–	–

In a preceding investigation on octenes we showed that the saturated hydrocarbons yield is closely related to the catalyst: starting material ratio (by volume). This is also supported by the data of Figure 1.

The amount of coke formed in these experiments is also closely dependent upon the catalyst amount, as shown in Fig. 2.

Inspection of Figures 1 and 2 clearly shows the relation between coke formation and amount of saturated hydrocarbons, and the relation between coke formation and amount of catalyst. We can infer from these diagrams that the absolute amount of coke formed per unit volume of catalyst is wholly dependent on the nature of the starting material.

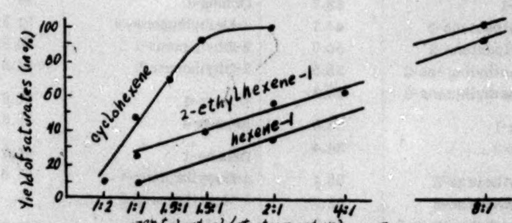

Figure 1. Saturation as a function of the catalyst volume (each experiment was performed with 50 ml hydrocarbons).

The process of coke formation (and in turn of saturated

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* The monomer fraction of these experiments contained 60% olefins and had n_D^{20} 1.3877. The initial substance (hexene-1) contained 14.24% hydrogen and 85.76% carbon.

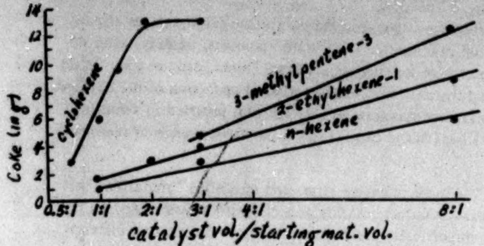
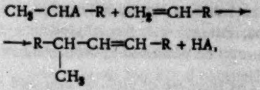


Fig. 2. Effect of amount of catalyst on coke formation

hydrocarbons formation) may thus be said to involve, firstly, formation of a certain amount of polymers (dimers and trimers) of the original hydrocarbon. Assuming the aluminosilicate to be in the form $(HAlSiO_4)_x$ (HA for short) – i.e., a compound with the properties of an inorganic acid and capable of exchanging hydrogen atoms with hydrogen atoms of the reacting hydrocarbon—then polymerization (say of hexene-1) might proceed as follows:

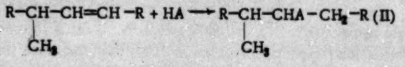
$$CH_2{=}CH-R + HA \rightarrow CH_3-CHA-R \quad (I)$$



$$CH_3-CHA-R + CH_2{=}CH-R \longrightarrow R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH{=}CH-R + HA,$$

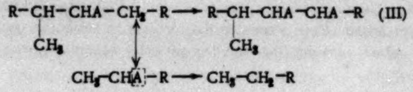
i.e. entirely in analogy with the Butlerov scheme for polymerization of olefins in presence of sulfuric acid.

A molecule of formed dimer can react afresh with catalyst:



$$R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH{=}CH-R + HA \longrightarrow R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CHA-CH_2-R \quad (II)$$

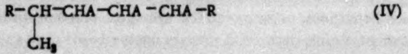
We can now suggest that reaction occurs between the complexes (II) (polymer molecules combined with catalyst) and (I) (monomer molecules combined with catalyst) to give molecules of paraffin hydrocarbon and of a complex (III) with a lower hydrogen content:



$$R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CHA-CH_2-R \longrightarrow R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CHA-CHA-R \quad (III)$$

$$CH_3-CH\boxed{A}-R \longrightarrow CH_3-CH_2-R$$

The process can later be repeated with formation of a fresh molecule of paraffin hydrocarbon and of a polymer-aluminosilicate complex (IV) still poorer in hydrogen:



$$R-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CHA-CHA-CHA-R \quad (IV)$$

On the average each polymer molecule can give 3-4 hydrogen molecules for the saturation of the monomer fraction. A series of data confirming this may be adduced. The deposits on the catalyst, according to Thomas [4], have the empirical formula $CH_{1.3}$. According to our determinations the elementary composition of the coke (C 91%, H 9%) corresponds to the empirical formula C_nH_{2n-8} (styrene type). The above conclusion that 1 g of formed saturated hydrocarbon corresponds to 0.45-0.52 g coke on catalyst is also in good agreement with the assumption that each polymer molecule yields 3-4 molecules of hydrogen for saturation.

It must be emphasized that the so-called coke contains a high proportion of hydrogen and that the name is purely arbitrary.

After releasing 3-4 molecules of hydrogen a small amount of the polymers may be desorbed (strictly speaking, detached from the catalyst) to form the aromatic hydrocarbons found in the catalyzate.

Support for the above mechanism of hydrogen rearrangement is also obtained in our studies of the dynamics of the processes taking place on the catalyst. By dynamic processes we understand the part played by individual transformations (isomerization, polymerization, yield of saturated hydrocarbons, yield of aromatic hydrocarbons) in the separate stages of an experiment. We carried out an investigation along these lines by spacing out an experiment for a period of 5 hours (instead of 100 minutes) and taking samples and investigating the products of transformation of each individual stage. The results of these investigations are as follows: During the first 40-60 minutes intensive saturation and isomerization occur, also much coke formation; products poor in hydrogen are absent from the polymers.

After 60 minutes coke formation terminates and formation of saturated products is insignificant and usually ceases after 80-100 minutes.

The most interesting feature is that aromatic hydrocarbons appear in the catalyzate (although, as already noted, only in the polymer fractions) only after a sharp drop in formation of saturated products, namely, after 60-80 minutes of catalyst operation. The fresh catalyst, most active for hydrogen rearrangement, did not give liquid aromatic hydrocarbons. The latter only appeared in the catalyzate after a certain period of operation of the catalyst which was already incapable of catalyzing hydrogen rearrangement reactions. We are thus justified in assuming that the appearance of small amounts of aromatic hydrocarbons in the catalyzates is the consequence of secondary reactions.

Let us revert now to the data of Tables 1 and 2. The more intensive saturation of olefins containing tertiary double bonds is evidently explained by the greater ease of polymerization of such hydrocarbons. According to Lebedev [6], for instance, only tetrasubstituted and asymmetrically disubstituted ethylene derivatives undergo polymerization over floridin. But symmetrically disubstituted, monosubstituted and tetrasubstituted olefins, according to Lebedev, do not polymerize over floridin. This accounts for the less intensive saturation of hexene-1 in comparison say, with 2-methylpentene-2, since the first stage of the hydrogen rearrangement process (polymerization) must be preceded by isomerization of the first hydrocarbon into the second.

The increase of yield of saturated products with increasing molecular weight of the initial hydrocarbon can be accounted for by the different properties of the polymers formed. Whereas the primary product of hexene polymerization (dodecene) is a gas under the experimental conditions and is relatively easily desorbed from the catalyst surface, decene dimer is bound to be tenaciously chemisorbed and precipitated on the catalyst. The intensified saturation of cycloolefins is directly related to their intensified polymerization. For example, in identical conditions, hexene-1 and cyclohexene yield respectively 17% and 28% polymers. Taking into consideration the same large difference in degree of coke formation (respectively 11% and 31%), then the more intensive polymerization of cycloolefins in comparison with open-chain olefins is obvious. We may add that the ease of catalytic transformations of cycloolefins does not apply only to polymerizations and hydrogen rearrangements; cycloolefins also undergo isomerization much more readily.

It is interesting to note that in the case of cycloolefins the yield of saturates did not increase with increasing molecular weight of the initial hydrocarbon. This is because the increase in molecular weight of cycloolefins was due to introduction of an aliphatic radical into the ring, and this naturally accentuated the olefinic as distinct from the ring structure

The process of hydrogen rearrangement is notable for the formation of saturated hydrocarbons containing a tertiary carbon atom, pointing to selective saturation of olefins with a tertiary double bond. Such a specific effect on the tertiary double bond is only exercised by aluminosilicates, since the numerous investigations of Lebedev [7] indicate that in normal hydrogenation conditions, using molecular hydrogen, monosubstituted olefins are saturated more intensively. Selective saturation of olefins containing tertiary double bonds plays an important part in the accumulation of branched hydrocarbons in the products of catalytic cracking. Thus the tertiary olefins formed by isomerization are rapidly saturated and thereby removed from the processes taking place at the catalyst.

EXPERIMENTAL

The study of the hydrogen rearrangement processes was carried out in an ordinary apparatus for the investigation of catalytic processes in a flow system. All the experiments were performed at 250°. The cracking experiments (octene-1) were performed in the same conditions but starting at 350°. The catalyst was a synthetic aluminosilicate cracking catalyst of the Houdry type. The conversion products consisted of liquid catalyzate (70-90% yield) and coke on the catalyst (10-30% yield). The coke was determined by weighing the catalyst before and after the experiment. The catalyzate was fractionally distilled to give the monomer of the original hydrocarbon (yield 50-80%) and higher boiling (polymer) fraction (10-30% yield). The amount of saturated products formed in the hydrogen rearrangement reaction was calculated on the basis of the bromine number of the monomer fraction. In each experiment 50 ml hydrocarbon was taken.

Aromatic hydrocarbons were determined by sulfonation with 100% sulfuric acid. The structural investigation of the formed saturated hydrocarbons is described in another paper and will therefore not be considered here.

In Table 4 are presented some data for the catalyzates. Experimental conditions were the same as in Table 1 and 2.

TABLE 4

Initial hydrocarbon	Yield (% of raw material)			Monomer n_D^{20}	Polymer n_D^{20}
	Monomer	Polymer	Coke		
Hexene-1	63	18	11	1.3877	1.4446
3-Methylpentene-3	63	16	14	–	–
2-Methylpentene-2	59	–	14	1.3815	1.4470
2,2-Dimethylbutene-3	57	16	11	1.3928	1.4430
Heptene-1	68	15	11	1.3980	1.4480
Heptene-3	65	–	12	1.3975	1.4455
Octene-1	63	13	–	1.4070	1.4560
3-Ethylhexene-3	63	12	15	1.4020	1.4565
Decene-1	43	8	34	–	–
Cyclohexene	50	30	15	1.4263	1.5012
1-Methylcyclohexene-1	57	22	–	1.4315	1.5050
1-Methylcyclohexene-3	57	20	–	1.4335	1.4960
1-Methylcyclopentene-1	40	40	12	1.4155	1.5015
1-Butylcyclopentene-1	57	13	–	1.4390	1.4960

All the hydrocarbons utilized in the research were usually obtained by dehydration of the corresponding alcohols. Primary and secondary alcohols were dehydrated over alumina, the primary ones at 375° and the secdary at 325°. Tertiary alcohols were dehydrated by slow distillation with iodine. 1-Alkenes were prepared from primary normal alcohols. They may possibly contain small amounts of 2-alkenes. 2-Methylpentene-2 was prepared from dimethylpropyl carbinol synthesized by a Grignard reaction from acetone and propyl magnesium bromide. 3-Methylpentene-3 was prepared from diethylmethyl carbinol (from methylethyl ketone and ethyl magnesium bromide). 2,3-Dimethylbutene-2 was prepared from dimethylisopropyl carbinol (from methylisobutyrate and methyl magnesium iodide). Heptene-3 and nonene-4 were prepared from the dialkyl carbinols synthesized from methyl formate and the corresponding alkyl magnesium bromides. 2-Methylpentene-2 was prepared from dimethylbutyl carbinol. This alcohol was derived from acetone and butyl magnesium bromide. 3-Methylpentene-3 was prepared from methylethylpropyl carbinol (from methylethyl ketone and propyl magnesium bromide). 2,4-Dimethylpentene-2 was obtained by dehydration of diisopropyl carbinol prepared by catalytic reduction of diisopropyl ketone. 2-Ethylhexene-1 was prepared from 2-ethylhexanol-1. 3-Ethylhexene-3 was prepared from diethylpropyl carbinol (from ethyl butyrate and ethyl magnesium bromide). 4-Methylheptene-3 was prepared from dipropylmethyl carbinol (from ethyl acetate and propyl magnesium bromide). 4-Propylheptene-3 was prepared from tripropyl carbinol (from ethyl butyrate and propyl magnesium bromide). 5-Methylnonene-4 was prepared from dibutylmethyl carbinol (from ethyl acetate and butyl magnesium bromide). Cyclohexene was prepared from cyclohexanol; 1-methylcyclohexene-1 from 1-methylcyclohexanol-1 (from cyclohexanone and methyl magnesium iodide); 1-methylcyclohexene-3 from hexahydro-p-cresol: 1-propylcyclohexene-1 from 1-propylcyclohexanol-1 (from cyclohexanol and propyl magnesium bromide). 1-Methylcyclopentene-1 was prepared from 1-methylcyclopentanol-1 (from cyclopentanone and methyl magnesium iodide). 1-Butylcyclopentene-1 was prepared from 1-butylcyclopentanol-1 (from cyclopentanone and butyl magnesium bromide). 5-Methylhexene and allylcyclohexane were got by condensation of the corresponding alkyl halides with allyl bromide (Grignard-Wurtz reaction).

The constants of the hydrocarbons (after purification in the usual manner by repeated fractionation over sodium and also in a column of ten theoretical plates) are presented in Table 5. (See next page)

The 1-alkenes may contain small amounts of 2-alkenes.

The data of Table 5 are in good agreement with those in the handbooks of Egloff [8] and Obolentsev[9].

SUMMARY

1. Hydrogen rearrangement in olefins over aluminosilicate in conditions excluding cracking was investigated.

2. Cyclic olefins are found to be more intensively saturated than open-chain olefins.

3. A mechanism is advanced for the formation of saturated hydrocarbons which involves transfer of hydrogen by the condensation products to the catalyst. The condensation products formed are probably polymers of the original hydrocarbon.

4. It is shown that the amount of saturated hydrocarbons formed is in direct relation to the amount of coke on the catalyst.

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TABLE 5

Hydrocarbon	B.p.	n_D^{20}	d_4^{20}	Bromine no.
Hexene-1	63-68	1.3900	0.6749	191
3-Methylpentene-3	68-69	1.4026	0.6952	190
2-Methylpentene-2	65-66	1.3965	0.6870	193
2,3-Dimethylbutene-2	70-72	1.4087	0.7108	177
2,2-Dimethylbutene-3	41-43	1.3765	0.6556	192
Heptene-1	93-94	1.4010	0.6982	162
Heptene-3	95-96	1.4030	0.7014	159
2-Methylhexene-2	94-95	1.4038	0.7120	157
3-Methylhexene-2	93-95	1.4105	0.7159	164
5-Methylhexene-1	84-85	1.3965	0.6926	165
2,4-Dimethylpentene-2	79-82	1.4010	0.6960	162
Octene-1	121-123	1.4122	0.7182	142
2-Ethylhexene-1	119-120	1.4168	0.7300	137
3-Ethylhexene-2	119-120	1.4205	0.7310	150
4-Methylpentene-3	118-120	1.4164	0.7306	142
Nonene-1	146-147	1.4167	0.7278	125
Nonene-4	145-146	1.4175	0.7308	125
Decene-1	171-172	1.4217	0.7421	113
5-Methylnonene-4	165-166	1.4286	0.7498	114
4-Propylheptene-3	156-158	1.4277	0.7598	114
Cyclohexene	82.5-83	1.4443	0.8109	196
1-Methylcyclohexene-1	110-111	1.4502	0.8147	163
1-Methylcyclohexene-3	102-103	1.4420	0.7998	167
1-Propylcyclohexene-1	150-152	1.4580	0.8410	110
1-Methylcyclopentene-1	75-76	1.4270	0.7761	194
Allylcyclohexene	148-151	1.4507	0.8088	118
1-Butylcyclopentene-1	155-157	1.4490	0.8110	142

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Academy of Sciences of the U.S.S.R.

REACTION OF BORON FLUORIDE ETHERATE WITH ORGANIC CARBOXYLIC ACIDS AND PHENOL

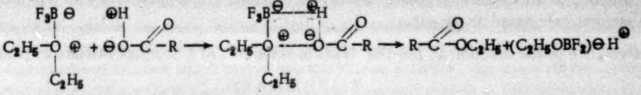
S. V. Zavgorodny

In textbooks of organic chemistry dialkyl ethers are usually described as very stable compounds [1] with low reactivity [2] and very difficult to bring into reaction [3]. At the present time this evaluation is inconsistent with what we know of compounds of this class. Dialkyl ethers are relatively reactive and in certain conditions enter into reaction with the most diverse reagents. Apart, for instance, from the well-known reactions with hydrogen halides, metallic sodium and organometallic compounds, they can be cleaved by organic carboxylic acids [4] and their anhydrides [5] and by acid chlorides [6] in presence of boron fluoride as catalyst.

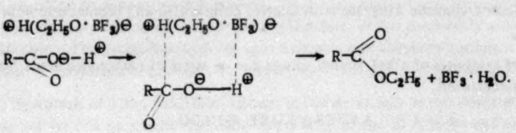
As far back as 1935-1936 [7], in a study of the addition of organic halo-substituted acids to olefins in presence of boron fluoride etherate, we noted that when this catalyst was employed in considerable amounts and the reaction proceeded for a long period at 100° very small amounts of ester-like products were formed which boiled at lower temperatures than the anticipated butyl or amyl esters of the acids. But at the time we did not concern ourselves with these products and they remained uninvestigated. In this paper we deal specially with the reaction of boron fluoride etherate with acetic, chloracetic and, bromacetic acids and with phenol, and we find that in the form of its complex with boron fluoride, diethyl ether is cleaved by the specified acids and by phenol to form the corresponding esters.

The probable reaction mechanism involves activation of the acid molecule by the initial dipole complex of boron fluoride with ether and the formation of a ternary complex in which both the ether and the acid possess heightened reactivity. Heat treatment results in cleavage of this complex into ester and boron fluoride-ethyl alcohol compound (scheme I). In certain conditions these may be the final products. When acid is present, however, it may happen that the very reactive compound of boron fluoride with ethyl alcohol will react further with the acid to form the ternary complex which then breaks down to ester and boron fluoride monohydrate (scheme II).

(I)



(II)


⊕H($C_2H_5O \cdot BF_3$)⊖
R—C—O⊖—$H^⊕$
O
⊕H($C_2H_5O \cdot BF_3$) ⊖
R—C—O ⊖ $H^⊕$
O
R—C
OC_2H_5 + $BF_3 \cdot H_2O$.

Thus one mole of ether may convert two moles of acid into ester. It must be remembered, however, that the reaction is more complex in practice than is represented by the two above schemes. Deposition on the test tube walls, above the layer of reaction mixture, of a white solid of inorganic origin, especially in experiments with prolonged heating at over 100°, is due to the action of hydrogen fluoride (possibly formed by decomposition of the boron fluoride-ethyl alcohol compound in accordance with the reaction $C_2H_5OH \cdot BF_3 \rightarrow C_2H_5OBF_2 + HF$ [9].). The degree of cleavage depends on the acid and increases in the order acetic-chloracetic-bromacetic. For example, on heating a 1:2 mixture of boron fluoride etherate and acetic acid for 20 hours on the boiling water bath, ethyl acetate is obtained in 21% yield. In similar conditions the ethyl ester of chloracetic acid is formed in 32% yield. On heating boron fluoride etherate with bromacetic acid in a ratio of 1:2 for 6 hours on an oil bath at 135-145°, the ethyl ester of bromacetic acid is obtained in 52% yield. Apart from its theoretical interest, the reaction here described may find practical application for ester syntheses.

EXPERIMENTAL

Preparation of ethyl acetate. Into a broad test tube is introduced glacial acetic acid and boron fluoride etherate. The mixture formed a light-brown transparent liquid. The test tube was closed with a rubber stopper and heated for 20 hours on the boiling water bath. The mixture turned almost black and opaque. After cooling, the test tube was opened and did not exhibit appreciable gas pressure. The reaction mixture was treated with 8% sodium hydroxide solution. The ester was separated, washed with water, dried with calcium chloride and distilled to give a colorless liquid with a pleasant odor. After a second distillation it had b.p. 76-78°; d_4^{18} 0.9023. 6.8 g acetic acid and 7.32 g boron fluoride etherate gave 1.47 g ethyl acetate or 21.3% (14.7% of the theoretical yield.*

Preparation of ethyl ester of monochloracetic acid. A mixture of 0.05 mole of chemically pure chloracetic acid and 0.05 mole boron fluoride etherate was heated for 20 hours on the water bath. No crystals separated after standing overnight and the mass remained in the form of a homogeneous dark-brown liquid. On opening the tube the liquid fumed and had a weak lachrymatory action. The product was worked up as before, dried with calcium chloride and distilled at atmospheric pressure. A few drops of ethyl ether came over up to 40°, after which the temperature rose quickly to 142° and the whole of the ester distilled as a colorless liquid at 144-146°; n_D^{14} 1.4280; d_{14}^{14} 1.1631. 7.82 g boron fluoride etherate and 9.5 chloracetic acid gave 2.95 g of ethyl ester of chloracetic acid or 31.8% (21.7%) of the theoretical yield.

Preparation of ethyl ester of bromacetic acid. The heterogeneous mixture of bromacetic acid (prepared by Higginbottom's method [8]) and boron fluoride etherate was heated for 6 hours on the oil bath at 135-145°. The mass was black and opaque. In the upper part of the reaction tube was formed a dense layer of white inorganic material. A slight detonation occurred when the tube was opened. The reaction mixture was worked up as before. The ester was a colorless, very lachrymatory, heavy liquid and distilled at atmospheric pressure at 164-169°. From 4.62 g boron fluoride etherate and 8.1 g bromacetic acid was obtained 3.62 g ethyl ester of bromacetic acid or 52.00% (34.4%) of the theoretical yield.

After a second distillation the ester had b.p. 167-168.5°, n_D^{14} 1.455; d_{14}^{14} 1.5134.

Preparation of phenetole. As in the experiments with acids, 4.92 g phenol and 3.46 g boron fluoride etherate were charged into a wide test tube. The phenol dissolved readily after brief shaking and the homogeneous liquid (tube stoppered) was heated for 12 hours on the boiling water bath. The mixture was then diluted with 8% sodium hydroxide solution and the ethereal product of the upper layer was treated with alkali solution until a drop of it on a watch glass no longer gave a turbidity with hydrochloric acid. The product was then washed with water, dried with potassium carbonate and distilled at atmospheric pressure. There was obtained 1.38 g phenetole with b.p. 170-172° or 33.6% of the theoretical amount calculated on the ether.

Performance of the reaction at 135-150° leads to formation of a complex mixture of products boiling at 230-275°.

SUMMARY

1. The reaction of boron fluoride etherate with acetic, chloracetic and bromacetic acids and phenol has been investigated.

2. The possibility of synthesis of alkyl phenol ethers and of esters of carboxylic acids from ethers in presence of boron fluoride has been established.

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* In all the later experiments the yield of esters is calculated on the ethyl ether according to scheme I (first number) and scheme II (value in brackets) or on the basis of the total amount of ether and acid used in the reaction.

SYNTHESIS OF ORGANOELEMENT COMPOUNDS OF THE ALIPHATIC SERIES BY THE DIAZO METHOD

III. SYNTHESIS OF COMPOUNDS OF GROUP IV ELEMENTS – ORGANOSILICON COMPOUNDS

A. Ya. Yakubovich and V. A. Ginsburg

Aliphatic diazo compounds can be successfully used, as we have shown, for the preparation of organic compounds of group V elements [1].

In the present communication we present the results of application of the diazo method to the synthesis of organoelement compounds of silicon – an element of the fourth group of Mendeleev's periodic system [2].

At the ordinary temperature silicon tetrachloride energetically, and sometimes explosively, decomposes diazomethane with evolution of nitrogen and formation of a solid, silicon-free product of polymerization of methylene radicals known as "polymethylene". But if the reaction is carried out at −55-45°, then polymethylene is not formed, or only formed to a limited extent, and the reaction products are organosilicon compounds which are obtained in 65-75% yields:

$$SiCl_4 + CH_2N_2 \longrightarrow ClCH_2SiCl_3 + N_2$$

$$ClCH_2SiCl_3 + CH_2N_2 \longrightarrow (ClCH_2)_2SiCl_2 + N_2 \text{ etc.}$$

It is easiest to effect introduction of one methylene group into the $SiCl_4$ molecule with formation of chlormethyltrichlorsilane. Introductions of second and further groups proceed with progressively increasing difficulty. Even more difficult is the methylenation of unsubstituted alkylchlorsilanes such as methyltrichlorsilane; the latter is formed with diazomethane with a small yield of chlormethyldichlormethylsilane. Trialkylchlorsilanes, for example triethylchlorsilane, are not methylenated at all by diazomethane. Diazoethane reacts in a similar manner to diazomethane but more energetically.

There is observed a correlation between the fall in yields of organosilicon compounds with increasing substitution of the chlorine in $SiCl_4$ by aliphatic radicals and the speed of decomposition of diazo compounds under the action of organosilicon halides, the speed falling sharply in the same sequence. In the case, for instance, of triethylchlorsilane, diazo compounds are decomposed with extraordinary slowness, and apparently only in presence of moisture in the diazomethane solution which hydrolyzes the silicon chloride. But even alkyltrichlorsilanes, for example CH_3SiCl_3, react with aliphatic diazo compounds and then decompose at low temperatures so slowly that catalysts must be added to accelerate the process. Suitable catalysts are strongly polar or surface-active substances whose field probably upsets the electronic equilibrium in the extremely unstable system of atoms of the polar diazo molecule. The latter breaks down into nitrogen and alkylene radicals. As catalyst we used copper bronze powder or anhydrous copper sulfate. Addition of catalyst accelerates the reaction 10-15 times.

The rate of hydrolysis of alkyl halides of silicon is known to fall in the order $RSiX_3$, R_2SiX_2, R_3SiX. This is probably bound up on the one hand with the reduced polarity of the Si-X bond and on the other hand with the growth of the screening effect of the alkyl groups. If this is so, then we can also account for the corresponding change in the effect of silicon alkyl halides on the decomposition of diazo compounds. This effect falls off in the above series of alkylhalosilanes, possibly for this reason.

With rise of reaction temperature to above −15° the rate of decomposition of the diazo compounds increases but the yields of organosilicon compounds sharply decrease since considerable amounts of "polymethylene" are formed due to the concurrent reaction of polymerization of the methylene radicals.

We therefore suggest that in the preparation of organosilicon compounds by the diazo method the free alkylene radical is formed but is attached to the Si-X bond and cannot polymerize. This hypothesis is consistent with the results of a study of the reaction of diazomethane with other silicon halides (fluorides and bromides).

Silicon tetrafluoride, which even in small amounts decomposes diazomethane, does not form organosilicon compounds with diazomethane. The Si-F bond energy is known to be very high (143 kcal). We may therefore assume that the activation energy of methylene polymerization is incomparably smaller than the reaction energy of methylenation of SiF_4, and consequently the reaction is exclusively directed towards polymethylene formation.

Reaction of diazomethane with silicon tetrabromide proceeds less energetically than that with the tetrachloride and at a lower velocity, but the ease of introduction of methylene groups increases since the Si-Br bond energy (69 kcal) is considerably lower than the Si-Cl bond energy (85.8 kcal). In this case the yields of organosilicon compounds increase and formationof di- and trialkylsilanes proceeds much more readily than with $SiCl_4$. Moreover, methylenation evidently continues to tetra-(brommethyl)-silane, but this compound could not be isolated in the pure state since it decomposes when distilled.

EXPERIMENTAL

a) Diazomethane and diazoethane were utilized in the form of 2.5-3% solutions in ether. These solutions were dried by freezing for 2-3 hours at −70° over solid KOH.

b) Silicon tetrachloride was distilled to remove hydrogen chloride.

c) Silicon tetrabromide. Dry bromine vapor was slowly passed at 500-520° through a tube filled with pellets of 70% Si-30% Fe alloy (ferrosilicon). The condensate – a light-colored, heavy, oily liquid – was fractionated. Traces of bromine were removed by shaking with mercury. Yield of substance with b.p. 151-153° was 65-75% calculated on the bromine used.

1. Preparation of chlormethyltrichlorsilane. To a solution of 85 g (1.5 mole) $SiCl_4$ in 100 ml dry ether at −45-55° was run in, with stirring, 13-14 g (1 mole) of diazomethane in 400 ml ether. The temperature in the reaction mixture must not be allowed to exceed the stated limits. The reaction is energetic and is accompanied by evolution of nitrogen (9 l. in all). After the color of diazomethane had disappeared and evolution of nitrogen had ceased, the temperature of the reaction mixture was slowly raised to room temperature and the ether and excess of $SiCl_4$ distilled off through a column. The residue was fractionated. Chlormethyltrichlorsilane has b.p. 116.5° at 750 mm; d_{20}^{20} 1.4776. Mobile colorless liquid with a pungent odor; hydrolyzes in the air.

> 4.440 mg, 4.930 mg substance: 1.020 mg, 1.185 mg CO_2. 0.495 mg, 0.695 mg H_2O. 0.4996 g substance: 0.1655 * g SiO_2. 12.850 mg, 11.920 mg substance: 13.85 ml, 12.85 ml 0.02 N $AgNO_3$. 0.0842 g, 0.3070 g substance: 13.35 ml, 50.05 ml 0.1 N $AgNO_3$.** 0.3760 g substance; 15.48 g benzene: Δt 0.674°. Found %: C 6.27, 6.52; H 1.25, 1.09; Si* 15.44; total Cl 76.53, 76.53; hydrolyzable Cl.** 57.32. 57.89; M 185. $ClCH_2SiCl_3$. Calculated %: C 6.52; H 1.09; Si 15.21; total Cl 77.11; hydrolyzable Cl 57.83; M 184.

The yield of chlormethyltrichlorsilane was 45-47% of theory (calculated on the diazomethane). The residue contained high-boiling chlormethylsilane chlorides (5-6 g) with b.p. 160-170°.

2. Preparation of di-(chlormethyl)-dichlorsilane $(ClCH_2)_2SiCl_2$. a) Using catalyst. To a mixture of 35 g (1 mole) chlormethyltrichlorsilane and 50 ml dry ether, cooled to −45-35°, is added 0.5 g finely pulverized anhydrous $CuSO_4$ and dropwise addition is made of half of a solution of 13.6 g (1.6 mole) diazomethane in 360 ml ether. The reaction is sluggish and is accompanied by evolution of nitrogen. After 3 hours the temperature in the reaction is raised to −20°, a further 0.5 g copper sulfate is added, and the second half of the diazomethane solution is added gradually (a portion being added when the color of the previous portion has disappeared). After about 8 l. nitrogen have come off, the reaction mixture is slowly brought to room temperature, the solution is filtered off from the separated polymethylene, and the ether distilled off in a column.

Several fractionations of the residue yielded di-(chlormethyl)-dichlorsilane with b.p. 58.5° at 16 mm; d_{20}^{20} 1.4624; 45% yield (based on diazomethane).

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* Silicon was determined gravimetrically as SiO_2. The sample was burned with a 1:1 mixture of nitric and sulfuric acids.

** Hydrolyzable chlorine was determined by titration of the aqueous hydrolyzate of the sample in ether.

4.670 mg substance: 2.095 mg CO_2; 0.965 mg H_2O. 0.5495 g substance: 0.1635 g SiO_2. 12.650 mg substance: 12.59 ml 0.02 N $AgNO_3$. 0.1277 g, 0.1608 g substance: 13.1 ml, 16.45 ml 0.1 N $AgNO_3$. 0.2376 g substance; 16.4 g benzene: Δt 0.370°. Found %: C 12.23; H 2.31; Si 13.85; total Cl 72.55; hydrolyzable Cl 36.13; M 200. $(ClCH_2)_2SiCl_2$. Calculated %: C 12.12; H 2.02; Si 14.14; total Cl 72.87; hydrolyzable Cl 35.86; M 198. The high boiling residue (80-90° at 15 mm) consisted of resinified products of further methylenation.

b) In absence of catalyst. A solution of 6.5 g diazomethane in 300 ml ether at −35-25° is gradually added to a mixture of 18.5 g $ClCH_2SiCl_3$ and 25 ml ether. After disappearance of the diazomethane color, the precipitate is filtered off and the ether distilled off in a column. Repeated fractionation gives di-(chlormethyl)-dichlorsilane with b.p. 57-59° at 16 mm in 30-35% yield (based on the diazomethane).

3. Preparation of tri-(chlormethyl)-chlorsilane $(ClCH_2)_3SiCl$. To 33 g (1 mole) di-(chlormethyl)-dichlorsilane in 50 ml ether is added 1 g anhydrous $CuSO_4$ and dropwise addition is made at −25-35° of 14.5 g (2 mole) of diazomethane in 400 ml ether; nitrogen is evolved and the original $(ClCH_2)_2SiCl_2$, which separates on cooling, goes into solution. The reaction is completed after 2 hours, the temperature of the mixture is then gradually brought to room temperature, the ethereal solution is filtered, and the ether distilled off in a column. Fractionation of the residue gives tri-(chlormethyl)-chlorsilane with b.p. 70° at 4 mm; d_{20}^{20} 1.4377. Yield 10-15% on the diazomethane.

3.380 mg, 4.680 mg substance: 2.100 mg, 2.920 mg CO_2; 1.065 mg, 1.350 mg H_2O. 15.380 mg, 9.490 mg substance: 14.17 ml, 8.75 ml 0.02 N $AgNO_3$. 0.1420 g, 0.1469 g substance: 6.90 ml, 7.10 ml 0.1 N $AgNO_3$. 0.3884 g substance; 16.0 g benzene: Δt 0.595. Found %: C 16.94, 17.01; H 3.52, 3.22; total Cl 65.30, 65.40; hydrolyzable Cl 17.25, 17.19; M 211. $(ClCH_2)_3SiCl$. Calculated %: C 16.98; H 2.83; total Cl 66.93; hydrolyzable Cl 16.72; M 212.

Residue in flask: A thick resin decomposing when heated.

4. Preparation of methyl-(chlormethyl)-dichlorsilane $CH_3Si(CH_2Cl)Cl_2$. a) Copper bronze as catalyst. 14.5 g (1.3 mole) diazomethane in 350 ml ether is added dropwise to 39 g (1 mole) methyltrichlorsilane in 40 ml ether. The reaction is started at −30° and then continues at −15°. The catalyst is 0.2 g powdered copper bronze. When the whole of the diazomethane had disappeared from solution (indicated by decolorization) the temperature was raised to room temperature; the solution was then filtered and the ether taken off through a column. Fractionation of the residue gave methyl-(chlormethyl)-dichlorsilane with b.p. 121-122°; d_{20}^{20} 1.2778. Yield 13% on the diazomethane. The substance was identical with that described by Krieble and Elliott [3]. Found % C 14.96, 14.80; H 3.20, 3.22; total Cl 70.85; hydrolyzable Cl 43.57, 43.76. $CH_3Si(CH_2Cl)Cl_2$. Calculated %: C 14.68; H 3.06; total Cl 71.34; hydrolyzable Cl 43.46.

b) Anhydrous $CuSO_4$ as catalyst. To 18 g CH_3SiCl_3 in 20 ml ether in presence of 0.5 g $CuSO_4$ is added dropwise at −30° 7.5 g diazomethane in 220 ml ether. Decomposition of the diazomethane is completed in one hour and the solution is then filtered, the ether taken off in a column and the residue fractionated. The 121-122° fraction of $CH_3Si(CH_2Cl)Cl_2$ is obtained in a yield of 12% of theory based on the diazo compound.

5. Reaction of diazomethane with triethylchlorsilane. To 15 g triethylchlorsilane in 25 ml ether in presence of 0.5 g $CuSO_4$ is added dropwise at −10-15° a solution of 12.5 diazomethane in 400 ml ether. After 3 hours the diazomethane has disappeared from the reaction mixture. The ether is then distilled off and the residue fractionated. 7 g of a fraction with b.p. 54° at 85 mm or 144° * (original chloride) was collected; also 5 g of a fraction with b.p. 104-110° at 10 mm, free from halogen. Repeated fractionation gave b.p. 101-102° at 9 mm (228° at 755 mm) which corresponds to the boiling point of triethylsilane oxide. Found %: C 57.70; H 11.98; M 238. $[(C_2H_5)_3Si]_2O$. Calculated %: C 58.54; H 12.14; M 246.

The same reaction was performed in the absence of catalyst in the course of a week at 0°; the same products were obtained.

6. Preparation of α-chlorethyltrichlorsilane $CH_3CHClSiCl_3$. To 84 g (2 mole) $SiCl_4$ in 100 ml ether is added dropwise, at −45-50° and with vigorous stirring, a solution of 14 g (1 mole) diazomethane in 450 ml ether. The reaction proceeds energetically with evolution of nitrogen (6.5 l.) and separation of a small amount of "polyalkylene". The reaction mixture is then brought to room temperature, the solution filtered and the

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* Pressure not stated — Publisher.

ether taken off in a column. Repeated distillation of the residue gave α-chlorethylchlorsilane with b.p. 66° at 75 mm; d_{20}^{20} 1.3919. Yield 35% based on the diazo compound. Found %: Si 14.32; total Cl 70.52; hydrolyzed Cl 51.18; M 187. $CH_3CHClSiCl_3$. Calculated %: Si 14.15; total Cl 71.68; hydrolyzed Cl 53.76; M 198.

Residue: Resinous organosilicon products; a large proportion (5-6 g) distilled in the range of 80° at 75 mm to 175° at 50 mm.

7 Preparation of brommethyltribromsilane $BrCH_2SiBr_3$. To 52 g $SiBr_4$ in 60 ml ether is added, at −55-60° and with stirring, 5.5-6 g (1.1 mole) diazomethane in 200 ml ether. The reaction proceeds energetically with evolution of 4 l nitrogen. After distilling off the ether the residue was distilled twice to give 29 g (55% yield) of brommethyltribromsilane; b.p. 70° at 6 mm; d_{20}^{20} 2.5730.

5.950 mg substance: 0.820 mg CO_2; 0.380 mg H_2O. 0.7920 g substance: 0.1368 g SiO_2. 0.0885 mg substance: 7.30 ml 0.1 N $AgNO_3$. 13.590 mg substance: 7.397 ml 0.02 N $AgNO_3$. 0.3012 g substance; 16.0 benzene; Δt 0.270°. Found %: C 3.75; H 0.74; Si 8.06; Br total 86.98; Br hydrolyzed 65.86; M 357.0. $BrCH_2SiBr_3$. Calculated %: C 3.33; H 0.55; Si 7.75; Br total 88.41; Br hydrolyzed 66.29; M 36.17.

Residue: High-boiling brommethylated organosilicon compounds distilling at up to 110° at 10 mm.

8. Preparation of di-(brommethyl)-dibromsilane $(BrCH_2)_2SiBr_2$. To 62 g (1 mole) $SiBr_4$ in 80 ml ether is added at −50° and with intensive stirring 13 g (1.8 mole) diazomethane in 400 ml ether. The reaction is rapidly completed with evolution of about 8.5 l nitrogen. After distilling off the ether the residue is fractionated. Di-(brommethyl)-dibromsilane with b.p. 107° at 9 mm and d_{20}^{20} 2.4614 is obtained in 55% of the theoretical yield (on diazomethane).

6.765 mg substance: 1.730 mg CO_2; 0.970 mg H_2O. 0.7294 g substance: 0.1218 g SiO_2. 12.605 g substance: 6.040 ml 0.02 N $AgNO_3$. 0.1736 g substance: 9.20 ml 0.1 N $AgNO_3$. 0.1811 g substance; 16 g benzene: Δt 0.155°. Found %: C 6.98; H 1.60; Si 7.81; Br total 83.21; Br hydrolyzed 42.35; M 375. $(BrCH_2)_2SiBr_2$. Calculated %: C 6.38; H 1.06; Si 7.45; Br total 85.09; Br hydrolyzed 42.54; M 375.6.

The high-boiling fraction consisted of organosilicon products distilling up to 120° at 5 mm.

9.. Preparation of tri-(brommethyl)-bromsilane $(BrCH_2)_3SiBr$. To 32 g (1 mole) $(BrCH_2)_2SiBr_2$ in 80 ml ether at −35-30° is added dropwise and with stirring 4.3 g (1.3 mole) diazomethane in 150 ml ether. Decomposition of the diazomethane is slow and is completed in 2-3 hours. The temperature is then raised to room temperature, the ether distilled off and the residue fractionated in vacuum, the last stage being accompanied finally by considerable decomposition. Tri-(brommethyl)-bromsilane with b.p. 122-123° at 5 mm and d_{20}^{20} 2.3440 is obtained in a yield of 40% (calculated on the diazomethane).

0.1642 g substance (2 hrs at 140° with 0.6 g Na in 5 ml alcohol): 16.75 ml 0.1 N $AgNO_3$. 0.3529 g substance (in ether, hydrolyzed with 25 ml water): 9.43 ml 0.1 N $AgNO_3$. 0.5740 g substance: 16 g benzene: Δt 0.485°. Found %: Br total 81.51; Br hydrolyzed 20.99; M 379. $(BrCH_2)_3SiBr$. Calculated %: Br total 82.02; Br hydrolyzed 20.50; M 389.6.

Residue: An organosilicon product decomposing when heated.

10 Preparation of tri-(brommethyl)-silane oxide $[(BrCH_2)_3Si]_2O$. 1 g of $(BrCH_2)_3SiBr$ on a watch glass is left overnight in the air. In the morning the mass crystallized. The crystals are pressed on porous tile and recrystallized from methanol. Needles with m.p. 69.5-70°. Quantitative yield.

4.700 mg substance: 2.000 mg CO_2; 0.760 mg H_2O. 0.9130 mg substance: 4.342 ml 0.02 N $AgNO_3$. 0.2035 g substance; 16 g benzene : Δt 0.120°. Found %: C 11.61; H 1.80; Br 75.99; M 618 *. $[(BrCH_2)_3Si]_2O$. Calculated %: C 11.32; H 1.88; Br 75.54; M 635.5.

SUMMARY

1. It is found that the diazo method of synthesis of aliphatic organoelement compounds can be successfully extended to the preparation of organosilicon compounds.

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* The cryoscopic constant for benzene is taken as 58.4 with allowance for the special characteristics of cryoscopic determination of molecular weights of the silane oxides (see [2]).

2. Silicon tetrachloride and silicon tetrabromide readily react with diazomethane and diazoethane to form primary, secondary and tertiary α-haloalkyl derivatives of silicon. Silicon tetrafluoride does not form organosilicon compounds by this reaction.

3. Alkylsilicon halides such as CH_3SiCl_3 and $(C_2H_5)_3SiCl$ enter with difficulty into reaction with aliphatic diazo compounds.

The reaction is facilitated by the use of powdered copper or copper salts, but even with their help triethylchlorsilane does not form compounds containing the α-haloalkyl radical.

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* See Consultants Bureau translation, p. 1569.

** See Consultants Bureau translation, p. 1575.

SYNTHESIS OF ORGANOELEMENT COMPOUNDS OF THE ALIPHATIC SERIES BY THE DIAZO METHOD

IV. SYNTHESIS OF COMPOUNDS OF THE GROUP IV ELEMENTS — ORGANOTIN COMPOUNDS

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It has been previously shown that with the help of aliphatic diazo compounds organo-arsenic, -antimony, -bismuth, -phosphorous, and -silicon compounds can be synthesized [1]. This communication describes the results of a study of the diazo method of synthesis of organotin compounds.

Haloalkyl derivatives of tin have not previously been described in the literature, with the exception of di-(β-chlorovinyl)-tin, prepared by A. N. Nesmeyanov and co-workers [2]. Attempts to prepare α-haloalkyl derivatives of tin by the diazo method were unsuccessful [3].

We found that in a benzene medium at 0 to 5° diazomethane normally reacts with tin tetrachloride to form the whole range of possible chloromethylated derivatives of tin in a yield of 30-40% (calculated on the diazomethane). Alkylation of tin proceeds very easily, and even with a ratio of 1.5 mole $SnCl_4$ to 1 mole diazomethane there is formed, side by side with chloromethyltrichloro tin, di-(chloromethyl)-dichlorotin, and tri-(chloromethyl)-chlorotin. The last compound has a boiling point close to that of dichloromethyltin and is separated from it with difficulty.

By treating chloromethyltrichlorotin or $SnCl_4$ with excess diazomethane (6 mole to 1 mole of chloride) it is possible to prepare tetrachloromethyltin in a yield of 50-60% (on the tin chloride). The following consecutive reactions may therefore be said to take place when diazomethane acts on $SnCl_4$:

$$SnCl_4 \xrightarrow[-N_2]{+CH_2N_2} ClCH_2SnCl_3 \xrightarrow[-N_2]{+CH_2N_2} (ClCH_2)_2SnCl_2 \xrightarrow[-N_2]{+CH_2N_2}$$

$$\longrightarrow (ClCH_2)_3SnCl \xrightarrow[-N_2]{+CH_2N_2} (ClCH_2)_4Sn.$$

Reaction of $SnBr_4$ with diazomethane proceeds in similar conditions even more readily and with high yields. With a 1:2 molar ratio the principal reaction products are: Di-(bromomethyl)-dibromotin and bromomethyltribromotin. Reaction of excess of diazomethane with di-(bromomethyl)-dibromotin (3:1) gives tetra-(bromomethyl)-tin.

Diazoethane acts on $SnCl_4$ in a similar manner to diazomethane. In this case, however, even with 2:1 molar ratio of $SnCl_4$ to diazoethane the main reaction product is di-(α-chloroethyl)-dichlorotin, together with tri-(α-chloroethyl)-chlorotin and α-chloroethyltrichlorotin (the latter is difficult to isolate in the pure form). Treatment of tri-(α-chloroethyl)-chlorotin with a large excess of diazoethane (1 mole of the tin compound to 3 moles of diazoethane) gives tetra (α-chloroethyl)-tin. Reaction of diazoethane with $SnCl_4$ may be represented by a scheme similar to that for diazomethane.

The main product of reaction of diazobutane with $SnCl_4$ in the molar ratio of 2:1 is di-(α-chlorobutyl)-dichlorotin:

$$2CH_3CH_2CH_2CHN_2 + SnCl_4 \longrightarrow (CH_3CH_2CH_2CHCl)_2SnCl_2 + 2N_2.$$

The diazo method makes possible the synthesis of organotin compounds containing various α-haloalkyl radicals or compounds containing both unsubstituted and α-halo radicals. For example chloromethyl-di-(α-chloroethyl)-chlorotin can be obtained by reacting chloromethyltrichlorotin with diazoethane:

$$ClCH_2SnCl_3 + 2CH_3CHN_2 \longrightarrow ClCH_2SnCl(CHClCH_3)_2 + 2N_2.$$

Di-(chloromethyl)-dichlorotin and diazoethane give di-(chloromethyl)-di-(α-chloroethyl)-tin:

$$(ClCH_2)_2SnCl_2 + 2CH_3CHN_2 \rightarrow (ClCH_2)_2Sn(CHClCH_3)_2 + 2N_2.$$

α-Chloroalkylchlorotin compounds are capable of entering normally into reaction with organomagnesium compounds to form mixed alkyl-α-chloroalkyl derivatives of tin. Thus, di-(α-chloroethyl)-dichlorotin with ethyl magnesium bromide gives di-(α-chloroethyl)-diethyltin:

$$(CH_3CHCl)_2SnCl_2 + 2C_2H_5MgBr \longrightarrow (CH_3CHCl)_2Sn(C_2H_5)_2 + 2MgClBr.$$

The above examples sufficiently clearly illustrate the general character of the reactions of tin halides containing tetravalent Sn with aliphatic diazo compounds. They represent a new synthesis of organotin compounds of the aliphatic series.

EXPERIMENTAL

1. Reaction of Diazomethane with Tin Tetrachloride

a) Preparation of chloromethyltrichlorotin and di-(chloromethyl)-dichlorotin side by side with trichloromethylchlorotin. To a solution of 34.5 ml (78.5 g or 0.3 mole) $SnCl_4$ in 50 ml dry benzene (thiophene-free), contained in a flask fitted with a mercury-sealed stirrer, a gas discharge, tube, a thermometer and dropping funnel, is added over a periodcof 1-1½ hours at -55° a benzene solution of diazomethane (9 g or 0.2 mole in 500 ml benzene) which has previously been dried for 1-1½ hours over potassium hydroxide pellets.

The energetic reaction is accompanied by nitrogen evolution and by the formation of a precipitate which dissolved there and then. The mixture was then left overnight. The precipitate was filtered off and the benzene distilled off in a good column. The residual benzene and $SnCl_4$ were distilled off without a column. The resultant dark, mobile oil (26 g), which fumes in the air, is vacuum-distilled. Chloromethyltrichlorotin (10.5 g) comesover at 70-78° at 5 mm; this was followed at 110-125° (5 mm) by a mixture of di-(chloromethyl)-dichlorotin and tri-(chloromethyl)-chlorotin (5.5 g). During the fractionation the dichloride begins to crystallize in the form of white needles. The residue is a solid dark resin (2 g).

Repeated fractionation of the 70-78° fraction at 5 mm yielded pure chloromethyltrichlorotin in the form of a heavy, colorless, oily liquid, fuming slightly in the air and gradually darkening in storage. B.p. 72.5-73° at 5 mm; d_{20}^{20} 2.31; n_D^{20} 1.5388; it mixes with the common solvents, dissolves in water and hydrolyzes.

0.2400 g, 0.2320 g substance: 25.9 ml, 25.02 ml 0.1 N $AgNO_3$. 10.365 mg, 11.780 mg substance: 7.36 ml, 8.49 ml 0.02 N $AgNO_3$. 5.920 mg, 5.670 mg substance: 1.085 mg, 1.065 mg CO_2; 0.850 mg, 0.735 mg H_2O. 0.4625 g, 0.8137 g substance: 21.32 benzene: Δt 0.405°, 0.720°. 0.4112 g substance: 0.2256 g SnO_2. Found %: C 5.00, 5.12; H 1.6, 1.45; Cl hydrolyzed 38.27, 38.24; total Cl 50.41, 51.65; Sn 43.12; M 274.5, 271.7. $ClCH_2SnCl_3$. Calculated %: C 4.37; H 0.73; Cl hydrolyzed 38.76; Cl total 51.66; Sn 43.23; M 274.5.

Di-(chloromethyl)-dichlorotin can be separated from its mixture with tri-(chloromethyl)-tin by removing the oil on a porous porcelain plate or by dissolving the mixture in boiling benzene, the dichloride then crystallizing out in the pure form.

Di-(chloromethyl)-dichlorotin crystallizes well from cyclohexane in the form of white rectangular prisms or from gasoline in the form of large, lustrous, white needles; it is readily soluble under normal conditions in benzene, alcohol and water. M.p. 89.5-90° (falling to 88°).

6.230 mg, 8.005 mg substance: 3.300 mg, 4.212 mg SnO_2. 6.615 mg, 8,305 mg substance: 2.060 mg, 2.570 mg CO_2; 1.070 mg, 1.135 mg H_2O. 0.1418 g, 0.1400 g substance: 9.83 ml. 9.73 ml 0.1 N $AgNO_3$.* 15.920 mg. 13.225 mg substance: 10.85 ml, 9.08 ml 0.02 N $AgNO_3$. 0.2516 g, 0.3416 g substance: 17.11 g benzene: Δt 0.25°, 0.34°. Found %: Sn 41.72, 41.75; C 8.51, 8.44; H 1.80, 1.53; Cl hydrolyzed 24.57, 24.65; total Cl 48.35, 48.70; M 301.1, 300.7. $(ClCH_2)_2SnCl_2$. Calculated %: Sn 41.13; C 8.51; H 1.39; Cl hydrolyzed 24.58; total Cl 49.22; M 288.53.

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* Hydrolyzable chlorine was determined by dissolving a weighed sample in water, then adding excess of 0.1 N $AgNO_3$ and back-titrating. Preliminary treatment of the solution of dichloride with caustic alkali would lead to too-high and variable results probably due to hydrolysis of the chlorine linked to carbon atoms.

Tri-(chloromethyl)-chlorotin in the slightly impure form could be isolated by fractionation of the above-described mixture obtained from three operations. Several fractionations (the dichloride comes off first) leaves an uncrystallizable oil – tri-(chloromethyl)-chlorotin: b.p. 138-140° at 5 mm; d_{20}^{20} 2.03; n_D^{20} 1.593.

The compound is soluble in common solvents and in water. Alkalization of the aqueous solution yields a precipitate soluble in excess alkali.

Found %: Cl hydrolyzed 11.66, 11.89; Cl total 43.65, 43.51. $(CH_2Cl)_3SnCl$. Calculated %: Cl hydrolyzed 11.74; Cl total 45.38.

30 g diazomethane gave 62 g of a mixture of chloromethyl derivatives (about 30% of the theoretical yield).

b) Preparation of tetra-(chloromethyl)-tin, preparation from chloromethyltrichlorotin and diazomethane. To a solution of 9 g chloromethyltrichlorotin in 25 ml benzene is gradually added, with stirring, a benzene solution of diazomethane (7.8 g in 270 ml or 1:6 molar ratio) at 3-6°. The mixture is left overnight. The excess of diazomethane is decomposed with anhydrous copper sulfate by gradual addition of the reaction solution with stirring to a suspension of 1 g $CuSO_4$ in 25 ml benzene. The residue is filtered off and the benzene distilled off in a column.

The residue of dark oil crystallized on cooling (8.5 g) and was distilled in vacuum when a colorless, rapidly crystallizing oil came over; this was tetra-(chloromethyl)-tin (5.5 g) with b.p. 147-150° at 8 mm. Yield 52% of the theoretical based on the chloromethyltrichlorotin.

Tetra-(chloromethyl)-tin is readily soluble in benzene and alcohol and insoluble in water. It crystallizes from gasoline (1:10) as well-formed lustrous, white needles. M.p. 49-49.5° (begins to fuse at 48°). B.p. 148.5° at 8 mm.

15.315 mg, 9.395 mg substance: 9.455 ml, 5.753 ml 0.02 N $AgNO_3$. 8.645 mg, 5.955 mg substance: 4.830 mg, 3.250 mg CO_2; 2.230 mg, 1.425 mg H_2O. 15.230 mg, 9.135 mg substance: 7.222 mg, 4.36 mg SnO_2. Found %: Sn 37.36, 36.60; C 15.23, 14.88; H 2.88, 2.68; Cl 43.80, 43.43 $(CH_2Cl)_4Sn$. Calculated %: Sn 37.49; C 15.16; H 2.53; Cl 44.8.

Preparation from tin tetrachloride and diazomethane. To a solution of 34.7 g (1 mole) $SnCl_4$ in 50 ml dry benzene was added, as described above, a solution of 33.4 g (6 mole) diazomethane in 850 ml benzene at 3-6°. The reaction mixture is left overnight. The excess of diazomethane was decomposed as above. The benzene was distilled off with the help of a dephlegmator and the residue fractionated in vacuum. Tetra-(chloromethyl)-tin came over at 170-174° (20 mm) as a rapidly crystallizing oil (24 g). The resin remaining in the flask decomposed when heated. M.p. of tetra-(chloromethyl)-tin is 48-49°. No depression of m.p. of a mixed sample with the tetra-(chloromethyl)-tin prepared as described above. Yield 57% of theory based on tin tetrachloride.

2. Reaction of Diazomethane with Tin Tetrabromide

a) Preparation of bromomethyltribromotin together with di-(bromomethyl)-dibromotin. To a solution of 91 g $SnBr_4$ (0.2 mole) in 60 ml benzene is added a dry benzene solution of diazomethane (17.5 g or 0.4 mole in 400 ml). The benzene solution was previously dried over potassium hydroxide pellets for 2 hrs. The diazomethane solution is added at 1-2°. The reaction proceeds energetically with vigorous evolution of nitrogen. The mixture is left overnight, filtered from the small precipitate, and distilled in vacuum to remove the benzene. The residual mixture (about 78 g) is distilled at 5 mm to give the following fractions: I) b.p. 70-135° (21.5 g); II) b.p. 155-160° (44.0 g); III) b.p. 165-180° (about 0.5 g); the residue of hard resin weighed 12.5 g.

After a second fractionation of the 70-135° fraction, pure bromomethyltribromotin (5 g) is isolated with b.p. 109° at 5 mm; it is a heavy colorless liquid with d_{20}^{20} 3.251; miscible with water and soluble in common organic solvents.

3.488 mg substance: 0.375 mg CO_2; 0.414 mg H_2O. 4.697 mg substance: 0.488 mg CO_2; 0.482 mg H_2O. 0.3308 g substance: 21.53 ml 0.1 N $AgNO_3$. 0.3936 g substance: 26.18 ml 0.1 N $AgNO_3$. 17.440 mg substance: 7.75 ml 0.02 N $AgNO_3$. 11.940 mg substance: 5.34 ml 0.02 N $AgNO_3$ 8.518 mg substance: 2.883 mg SnO_2. 7.705 mg substance: 2.585 mg SnO_2. Found %: C 2.93, 2.82; H 1.32, 1.15; Br hydrolyzed 52.0, 52.15; Br total 71.16, 71.50; Sn 26.66, 26.42; $BrCH_2SnBr_3$. Calculated %: C 2.65; H 0.43; Br hydrolyzed 53.0; Br total 70.3, Sn 26.23.

The colorless, rapidly crystallizing di-(bromomethyl)-dibromotin (44 g) comes over at 155-160°; it crystallizes from benzene as large, white rectangular prisms with m.p. 87°; readily soluble in water and common solvents.

4.492 mg substance: 0.905 mg CO_2; 0.618 mg H_2O. 4.926 mg substance: 1.022 mg CO_2; 0.630 mg H_2O 18.670 mg substance: 8.19 ml 0.02 N $AgNO_3$. 14.230 mg substance : 6.39 ml 0.02 N $AgNO_3$. 0.4320 g substance: 18.24 ml 0.1 N $AgNO_3$. 0.1322 g substance: 5.62 ml 0.1 N $AgNO_3$. 5.395 mg substance: 1.714 mg SnO_2. 4.720 mg substance: 1.490 mg SnO_2. Found %: C 5.49, 5.65; H 1.43, 1.50; Br hydrolyzed 33.8, 33.9; Br total 71.80, 71.82, Sn 25.02, 24.87. $(BrCH_2)_2SnBr_2$. Calculated %: C 5.18; H 0.87; Br hydrolyzed 34.0; Br total 68.7 ; Sn 25.4.

Some material came over at 165-180°, but severe decomposition then started. A second fractionation of the 165-180° fraction gave a substance boiling at 165°, containing 18.8% hydrolyzable bromine and composed evidently of impure tri-(bromomethyl)-bromotin.

b) Preparation of tetra-(bromomethyl)-tin from di-(bromomethyl)-dibromotin and diazomethane. To a solution of 40 g di-(bromomethyl)-dibromotin in 50 ml dry benzene is added with stirring a solution of 12.8 g diazomethane in 500 ml benzene (molar ratio 1:3) at 3-2°. The reaction mixture was left overnight. The diazomethane excess was decomposed as before. The solution is filtered from precipitate, the benzene is distilled off on a water bath at 30-40° in vacuum. White crystals of tetra-(bromomethyl)-tin in the flask are impregnated with resin. The latter is washed out with benzene and the residual tetra-(bromomethyl)-tin crystallizes nicely from gasoline in the form of lustrous white needles with m.p. 57° (yield 25 g). Readily soluble in the common solvents and insoluble in water.

6.230 mg substance: 2.410 mg CO_2; 0.850 mg H_2O. 4.580 mg substance: 1.725 mg CO_2; 0.775 mg H_2O. 10.55 mg substance: 4.83 ml 0.02 N $AgNO_3$. 6.140 mg substance: 1.818 mg SnO_2. 4.989 mg substance: 1.506 mg SnO_2. Found %: C 10.54, 10.28; H 1.52, 1.89; Br 65.61; Sn 23.78, 23.33 $(BrCH_2)_4Sn$. Calculated %: C 9.82; H 1.64; Br 65.5; Sn 24.2.

3. Reaction of Diazoethane with Tin Tetrachloride

a) Preparation of di-(α-chloroethyl)-dichlorotin and tri-(α-chloroethyl)-chlorotin. To a solution of 220 g $SnCl_4$ (0.85 mole) in 150 ml dry benzene is slowly added from a dropping funnel a dry benzene solution of diazoethane (24 g or 0.43 mole in 800 ml benzene). The diazoethane solution was previously dried for 2 hours over potassium hydroxide pellets. Addition of diazoethane is effected over a period of 2.5 hours at 2-4°. The mixture is left overnight, then filtered from the small precipitate, and the benzene distilled off in a column. The residues of benzene and $SnCl_4$ are distilled off without a column; the vapor temperature rises to 116°. The resultant highly mobile liquid (70 g), fuming strongly in the air, is fractionated at 4 mm to give the following fractions: I) B.p. up to 60°, 11.3 g (contains $SnCl_4$); II) b.p. 60-104°, 18.1 g; III) b.p. 105-116°, 27.8 g; IV) b.p. 125-136°; residue 5.5 g.

A second fractionation of fraction II gave a substance with b.p. 69-71°. Judging by the analysis this is α-chloroethyltrichlorotin contaminated with di-(α-chloroethyl)-dichlorotin. Isolation of pure chloroethyltrichlorotin was made difficult by the small amount of material.

13.52 mg substance: 8.831 ml 0.02 N $AgNO_3$. 13.01 mg substance: 8.47 ml 0.02 N $AgNO_3$. 3.688 mg, 3.498 mg substance: 1.380 mg, 1.318 mg CO_2; 1.007 mg, 0.883 mg H_2O. 11.49 mg, 11.760 mg substance: 5.675 mg, 5.730 mg SnO_2; 0.1443 g substance: 14.19 ml 0.1 N $AgNO_3$. Found %: C 10.20, 10.27; H 3.05, 2.82; Cl total 46.33, 46.17; Cl hydrolyzed 34.87; Sn 38.90, 38.42. $(CH_3CHCl)SnCl_3$. Calculated %: C 8.30; H 1.37; Cl 49.0; Cl hydrolyzed 36.9; Sn 41.4.

A second fractionation of the third fraction at 4 mm gave 10.5 g di-(α-chloroethyl)-dichlorotin with b.p. 112° at 4 mm: A colorless oily liquid, darkening on standing in the air; d_{20}^{20} 1.829; n_D^{20} 1.5535; crystallizes in white crystals with m.p. 12°.

0.0902 g, 0.0874 g substance : 5.6 ml, 5.45 ml 0.1 N $AgNO_3$. 8.91 mg, 14.49 mg substance: 5.58 ml 9.052 ml 0.02 N $AgNO_3$. 5.715 mg, 5.080 mg substance: 3.30 mg, 2.875 mg CO_2; 4.420 mg, 1.37 mg H_2O. 0.3645 g substance: 0.1758 g SnO_2. 0.1771 g, 0.1252 g substance; 20 g benzene: Δt 0.140°, 0.10°. Found %: C 15.43, 15.39; H 2.78, 3.01; Cl total 44.41, 44.30; Cl hydrolyzed 22.10, 22.08; Sn 37.75; M 320.5, 323.8 $(CH_3CHCl)_2SnCl_2$. Calculated %: C 15.16; H 2.54; Cl total 44.8; Cl hydrolyzed 22.42; Sn 37.48; M 316.7.

A second fractionation of fraction IV gave tri-(chloroethyl)-chlorotin (7.5 g) with b.p. 130° at 3 mm; a colorless oily liquid, easily soluble in the common solvents; d_{20}^{20} 1.684; n_D^{20} 1.5450.

5.100 mg substance: 3.895 mg CO_2; 1.640 mg H_2O. 18.015 mg, 15.38 mg substance: 10.16 ml, 8.731 ml 0.02 N $AgNO_3$. 0.1550 g substance: 4.94 ml 0.1 N $AgNO_3$. 7.226 mg, 7.650 mg substance: 3.12 mg, 3.335 mg SnO_2. 0.1520 mg substance; 20 g benzene: Δt 0.115°. Found %: C 20.89; H 3.59; Cl total 40.00, 40.26; Cl hydrolyzed 11.3; Sn 34.01, 34.34; M 338.0 $(CH_3CHCl)_3SnCl$. Calculated %: C 20.88; H 3.48; Cl total 41.16; Cl hydrolyzed 10.3; Sn 34.43; M 344.6.

b) Preparation of tetra-(chloroethyl)-tin. To 26 g tri-(chloroethyl)-chlorotin, containing a small amount of di-(chloroethyl)-dichlorotin, in 50 ml dry benzene is gradually added 13.5 g diazoethane in 500 ml benzene at 2-3° (molar ratio of 1:3). Nitrogen is evolved energetically at first; after addition of 4 g diazoethane the evolution of nitrogen ceases. The temperature of the reaction mixture is brought to room temperature and the diazoethane is added at 15°. The mixture is left overnight, filtered from the small precipitate, and the benzene distilled off at 30-35° in vacuum. The remaining liquid (about 24 g), dark in color, is distilled in vacuum. The main portion (15.7 g) came over at 140-145° (3 mm); the residue (6.5 g) is a brown hard resin. A second distillation of the fraction yielded tetra-(chloroethyl)-tin (9.3 g) with b.p. 142° at 2 mm; very mobile, slightly colored liquid, readily soluble in common solvents; d_{20}^{20} 1.568; n_D^{20} 1.5365.

5.800 mg, 3.640 mg substance: 5.475 mg, 3.460 mg CO_2; 1.935 mg, 1.275 mg H_2O. 6.295 mg, 6.595 mg substance: 2.59 mg, 2.695 mg SnO_2. 10.025 mg substance: 5.98 ml 0.02 N $AgNO_3$ 15.010 mg substance: 7.774 ml 0.02 N $AgNO_3$. 0.2672 g, 0.6394 g substance; 20 g benzene: Δt 0.190, 0.450°. Found %: C 25.75, 26.91; H 3.73, 3.91; Cl 36.73, 37.37; Sn 32.41, 32.19; M 362.0, 363.7. $(CH_3CHCl)_4Sn$. Calculated %: C 26.0; H 4.30; Cl 38.2; Sn 31.8; M 372.5.

c) Preparation of di-(α-chloroethyl)-tin oxide. To a solution of 1 g di-(α-chloroethyl)-dichlorotin in 7 ml ethyl alcohol with stirring is added, dropwise, aqueous ammonia until the reaction is weakly alkaline. After 30 minutes the mixture is heated to boiling, the precipitate removed at the pump, washed with a little alcohol, and dried at 60-70°. Di-(α-chloroethyl)-tin oxide is a finely crystalline white powder with m.p. 180°. Yield 0.6 g.

Found %: C 18.70, 18.87; H 3.52, 3.85; Cl 27.48, 28.78; Sn 45.14, 45.35 $(CH_3CHCl)_2SnO$. Calculated %: C 18.34; H 3.08; Cl 27.10; Sn 45.30.

4. Reaction of Diazobutane with Tin Tetrachloride

Preparation of di-(α-chlorobutyl)-dichlorotin. To a solution of 46.5 g $SnCl_4$ in 50 ml dry benzene is added 7.5 g diazobutane in 480 ml benzene (molar ratio of 2:1) at 1°. The mixture is left overnight, filtered from a small precipitate, and the benzene taken off in vacuum at 30°. The residue (about 19.5 g) is fractionated in vacuum at 5 mm when the following fractions were obtained: I) b.p. 70-110°, 5.7 g; II) b.p. 110-145°, 8.3 g; residue of 5.4 g of dark, solid resin. A second distillation of fraction II gave 5.0 g with b.p. 134° at 5 mm which crystallized in the condenser and consisted, judging by the analysis, of di-(chlorobutyl)-dichlorotin; white crystals with m.p. 53°, readily soluble in common solvents.

4.635 mg substance: 4.480 mg CO_2; 1.760 mg H_2O. 3.960 mg substance: 3.825 mg CO_2; 1.515 mg H_2O. 10.42 mg substance: 5.521 ml 0.02 N $AgNO_3$. 13.70 mg substance: 7.327 ml 0.02 N $AgNO_3$. 0.1486 g substance: 0.0624 g SnO_2. Found %: C 26.35, 26.35; H 4.25, 4.18; Cl total 37.58, 37.93; Sn 32.6 $(CH_3CH_2CH_2CHCl)_2SnCl_2$. Calculated %: C 25.8; H 4.28; Cl total 38.00; Sn 31.83.

5. Preparation of Derivatives of Tetravalent Tin with Mixed Radicals

a) Preparation of chloromethyl-di-(α-chloroethyl)-chlorotin. To a solution of 20 g chloromethyltrichlorotin in 50 ml dry benzene is added a benzene solution of diazoethane (9.1 g in 400 ml, molar ratio 1:2) at 2-3°. The mixture is left overnight, then filtered from the small oily deposit, and the benzene taken off at 30-35° in vacuum. The residue (about 30 g), a dark, oily liquid, is distilled in vacuum.

Between 110 and 125° (at 3 mm) 2.8 g material comes over. The main bulk of product (22.75 g) distilled at 126-128° (3 mm). The residue is a dark, viscous resin (4.8 g). A second distillation of the 126-128° fraction gives pure chloromethyl-di-(α-chloroethyl)-chlorotin with b.p. 128° at 3 mm; d_{20}^{20} 1.765; n_D^{20} 1.555; a colorless oily liquid soluble in organic solvents. Yield 10.5 g.

7.195 mg, 5.015 mg substance: 4.700 mg, 3.235 mg CO_2; 2.160 mg, 1.535 mg H_2O. 13.030 mg substance: 7.654 ml 0.02 N $AgNO_3$. 13.210 mg substance: 7.852 ml 0.02 N $AgNO_3$. 10.385 mg, 8.952 mg substance: 4.785 mg, 4.093 mg SnO_2. 0.2275 g, 0.3352 g substance: 20 g benzene: Δt 0.190, 0.270°. Found %: C 17.81, 17.59; H 3.36, 3.42; Cl 41.66, 42.13; Sn 36.31, 36.01; M 320, 315. $(CH_3CHCl)_2SnClCH_2Cl$. Calculated %: C 18.4; H 3.30; Cl 42.94; Sn 35.90; M 330.

b) Preparation of di-(chloromethyl)-di-(α-chloroethyl)-tin. To a solution of 10 g di-(chloromethyl)-dichlorotin (1 mole) in 50 ml dry benzene is added a solution of 8.5 g diazoethane (4 moles) in 300 ml benzene at 2-4°. Nitrogen evolution ceases after about 3 g diazoethane has been added. The temperature is then raised to room temperature and the diazoethane is added at 10-12°. The mixture is left overnight, filtered from the precipitate, the benzene is distilled off in vacuum at 30-35° and the residue fractionated in vacuum. 2.8 g comes over at 141-145° (5 mm). The residue (5 g) decomposes with further heating. After a second distillation, the 141-145° fraction yields di-(chloromethyl)-di-(chloroethyl)-tin with b.p. 141-142° at 5 mm; oily colorless liquid, soluble in organic solvents; d_{20}^{20} 1.675; n_D^{20} 1.578.

Found %: C 21.81, 21.52; H 3.59, 3.54; Cl 40.63, 39.07; Sn 34.82, 33.68; M 338. $(CH_3CHCl)_2Sn(CH_2Cl)_2$. Calculated %: C 20.88; H 3.48; Cl 41.13; Sn 34.43; M 344.7.

c) Preparation of di-(α-chloroethyl)-diethyltin. To cooled Grignard reagent (3 g Mg, 13.5 g ethyl bromide and 37.5 ml absolute ether) with constant stirring and cooling is rapidly added 10 g di-(α-chloroethyl)-dichlorotin. The mixture is refluxed for 3 hours on the water bath, part of the ether is driven off and the residue decomposed with water, then with saturated ammonium chloride solution and finally with hydrochloric acid. To the resultant mixture is added ether and the layers separated. The aqueous layer is subjected to two further extractions with a little ether, and the ethereal solution is dried over calcined sodium sulfate. The ether is driven off and the residue (about 7 g) is fractionated in vacuum. The main amount (3.5 g) comes over at 114-155° (6 mm); the residue of 0.8 g is a viscous oil which decomposes when heated. A second distillation gives a product at 114-155° (5 mm). Pure di-(α-chloroethyl)-diethyltin is a readily mobile, colorless liquid; d_{20}^{20} 1.414; n_D^{20} 1.5083; soluble in organic solvents. Found %: C 30.62, 30.97; H 6.56, 6.33; Cl 22.85, 22.88; Sn 38.25, 38.13; M 308, 303. $(CH_3CHCl)_2Sn(C_2H_5)_2$. Calculated %: C 31.16; H 5.92; Cl 23.45; Sn 39.2; M 303.7.

SUMMARY

1. It is shown that the diazo method of synthesis of aliphatic organoelement compounds can be successfully extended to organotin compounds.

2. A new diazo synthesis is developed for α-haloalkyl derivatives of tin by reaction of halogenated derivatives of tetravalent tin with aliphatic diazo compounds.

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* See Consultants Bureau English translation, p. 1569.

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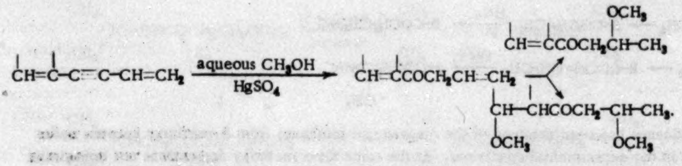
ACETYLENE DERIVATIVES

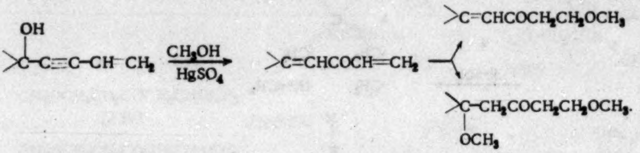
147. SYNTHESIS OF β-AMINO KETONES BY THE ACTION OF SECONDARY AMINES ON β-METHOXY KETONES

I. N. Nazarov and S. A. Vartanyan

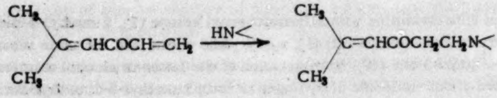
It has been shown in our laboratory that in the hydration of divinylacetylenic hydrocarbons in aqueous methanol in presence of mercuric sulfate, vinylallyl ketones are readily obtained which in the experimental conditions add on one or two molecules of methanol and are converted into the corresponding β-methoxy ketones [1]:



In another investigation in our laboratory it was shown that in presence of mercuric sulfate in methanol solution, vinylethinyl carbinols readily isomerize to divinyl ketones which in the experimental conditions add on methanol and are likewise converted into the corresponding β-methoxy ketones [2]:



β,β-Dimethyldivinyl ketone readily adds on secondary amines (diethylamine, piperidine) at the unsubstituted vinyl group with formation of unsaturated ketoamines [3]:

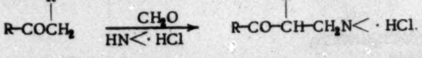


Similarly secondary amines add on to alkylvinyl ketones to form alkyl-β-aminoethyl ketones [4]:

$$\mathrm{R{-}COCH{=}CH_2 \xrightarrow{HN<} R{-}COCH_2CH_2N<}$$

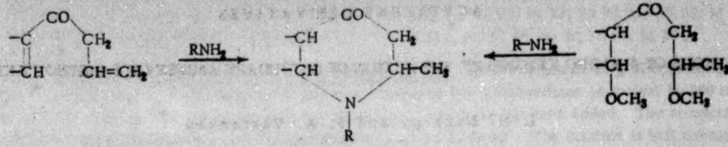
$$\mathrm{R = CH_3, C_2H_5}$$

β-Amino ketones can also be obtained by the Mannich reaction [5] — action of secondary amine hydrochlorides in aqueous formaldehyde solution on saturated ketones:



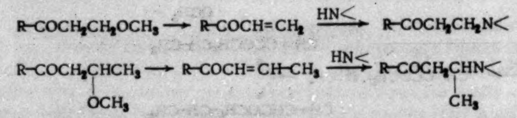
$$\mathrm{R{-}CO\overset{R'}{\overset{|}{C}}H_2 \xrightarrow[HN<\cdot HCl]{CH_2O} R{-}CO{-}\overset{R'}{\overset{|}{C}}H{-}CH_2N< \cdot HCl}$$

β-Amino ketones have recently been widely applied in the synthesis of diverse physiologically active substances [6], and therefore the development of simple methods of preparation of β-amino ketones may have great significance for the further progress of work on the discovery and synthesis of new pharmaceutical chemical preparations and medicinal products. For the preparation of β-amino ketones we decided first of all to utilize the above-mentioned readily accessible β-methoxy ketones, on the basis of which had already been developed in our laboratory a new and simple method of preparation of diverse γ-piperidones [7]:



It was found that β-methoxy ketones readily react also with secondary amines to form the corresponding β-amino ketones in high yields, which are also obtained by direct addition of amines to α,β-unsaturated ketones.

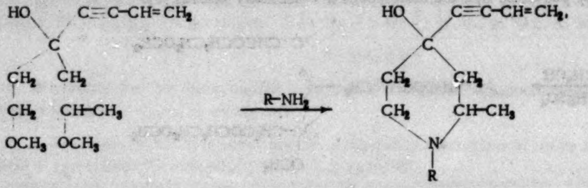
The reaction of amines with β-methoxy ketones is facilitated in presence of water and it proceeds in all probability via the cleavage of methanol from the β-methoxy ketones followed by addition of the amine at the double bond of the unsaturated ketone:



$$R{-}COCH_2CH_2OCH_3 \longrightarrow R{-}COCH{=}CH_2 \xrightarrow{HN<} R{-}COCH_2CH_2N<$$

$$R{-}COCH_2\underset{\displaystyle OCH_3}{\underset{|}{C}}HCH_3 \longrightarrow R{-}COCH{=}CH{-}CH_3 \xrightarrow{HN<} R{-}COCH_2\underset{\displaystyle CH_3}{\underset{|}{C}}HN<$$

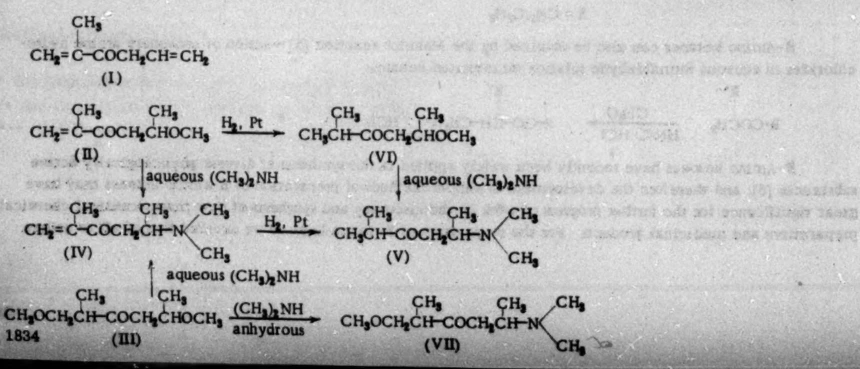
Experimental evidence has been obtained of the cleavage of methanol from β-methoxy ketones under the influence of amines in our experimental conditions. At the same time methoxy derivatives not containing a carbonyl group in the β-position and not susceptible to easy cleavage of methanol do not enter into reaction with ammonia and amines. Thus, for example, all our attempts to realize the reaction:



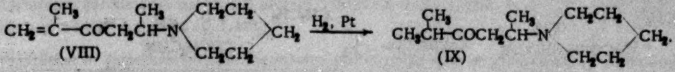
remained unsuccessful; the methoxy groups did not enter into reaction with ammonia even when heated (4 hours at 80°), and the dimethoxy carbinol was almost entirely recovered unchanged [8].

By reacting an aqueous solution of dimethylamine with allylisopropenyl ketone (I), 2-methyl-5-methoxy-1-hexen-3-one (II) and 1,5-dimethoxy-2-methylhexan-3-one (III) [1], a 60% yield of one and the same substance is obtained — 2-methyl-5-dimethylamino-1-hexen-3-one (IV); hydrogenation of the latter in alcohol solution in presence of Pt-catalyst results in absorption of one molecule of hydrogen to form 2-methyl-5-dimethyl-aminohexan-3-one (V).

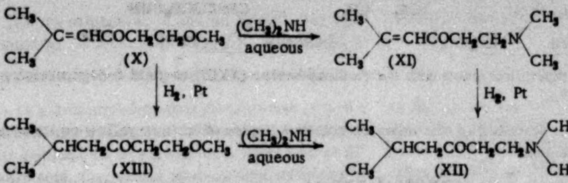
This ketone is also obtained by acting with aqueous dimethylamine on 2-methyl-5-methoxyhexan-3-one (VI) [1]:



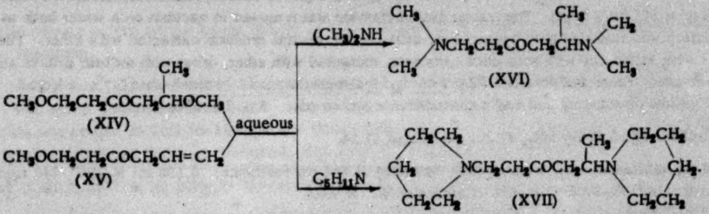
However, reaction of gaseous dimethylamine with the dimethoxy ketone (II) in an anhydrous medium gives 1-methoxy-2-methyl-5-dimethylaminohexan-3-one (VII) with retention of the methoxy group. These results show that water in the reaction mixture facilitates the cleavage of methanol from β-methoxy ketones, and this fact also explains its accelerating effect on this reaction. Reaction of aqueous piperidine solution with ketones (I, II, III) also gives one and the same substance in the shape of 2-methyl-5-N-piperidyl-1-hexen-3-one (VIII), hydrogenation of which in alcoholic solution in presence of Pt-catalyst leads to absorption of one molecule of hydrogen to form 2-methyl-5-N-piperidylhexan-3-one (IX):



Treatment of 2-methyl-6-methoxy-2-hexen-4-one (X) with aqueous dimethylamine [2] gives 2-methyl-6-dimethylamino-2-hexen-4-one (XI), hydrogenation of which in alcohol in presence of Pt absorbs one molecule of hydrogen to form 2-methyl-6-dimethyl-amino-hexan-4-one (XII). This amino ketone is also obtained by the action of dimethylamine on 2-methyl-6-methoxyhexan-3-one (XIII) [2,8]:

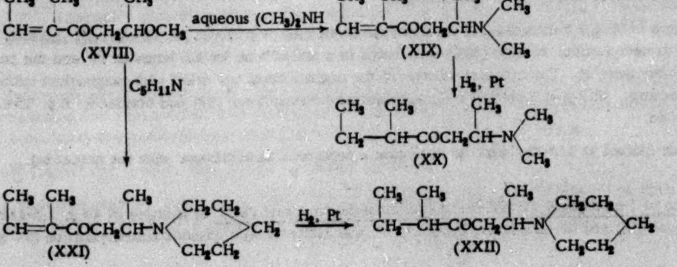


Reaction of dimethylamine with 1,5-dimethoxyhexan-3-one (XIV) and with 1-methoxy-5-hexen-3-one (XV) [9] gives a good yield of 1,5-bis-dimethylaminohexan-3-one (XVI):



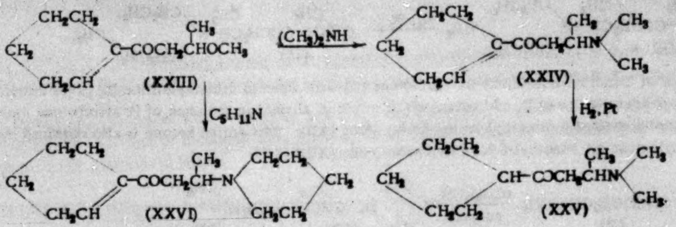
Reaction of aqueous solution of piperidine with ketones (XIV) and (XV) gives 1,5-bis-(N-piperidyl)-hexan-3-one (XVII) in good yield.

An aqueous solution of dimethylamine acts on 3-methyl-6-methoxy-2-hepten-4-one (XVIII) [10] to give, in a yield of about 55%, 3-methyl-6-dimethylamino-2-hepten-4-one (XIX). On hydrogenation in alcoholic solution in presence of Pt-catalyst, this amino ketone absorbs one molecule of hydrogen to form 3-methyl-6-dimethylamino-heptan-4-one (XX):



Piperidine acts on the methoxy ketone (XVIII) to form 3-methyl-6-(N-piperidyl)-2-heptan-4-one (XXI). This amino ketone hydrogenates in alcoholic solution in presence of Pt-catalyst to give 3-methyl-6-(N-piperidyl)-heptan-4-one (XXII).

Aqueous dimethylamine acts on allylcyclohexenyl ketone, also on its corresponding methoxy ketone (XXIII) [11], to give β-dimethylaminopropylcyclohexenyl ketone (XXIV). On hydrogenation in alcohol in presence of Pt-catalyst this amino ketone absorbs one molecule of hydrogen to form cyclohexyl-β-dimethylaminopropyl ketone (XXV):



An aqueous solution of piperidine reacts with the methoxy ketone (XXIII) to yield β-N-piperidylpropylcyclohexenyl ketone (XXVI).

All the β- amino ketones described in this paper are colorless liquids which turn yellow on standing and have a characteristic amine odor.

EXPERIMENTAL

Preparation of 2-methyl-5-dimethylamino-1-hexen-3-one (IV). a) 100 g 2-methyl-5-methoxy-1-hexen-3-one (II) (b.p. 54-59° at 6 mm; n_D^{20} 1.4400) [1] and 240 g 33 % aqueous dimethylamine solution were heated in an autoclave at 80° for 7 hours. The excess dimethylamine was removed in vacuum on a water bath at 45°. The solution was acidified with hydrochloric acid and the neutral products extracted with ether. The organic bases were salted out with potassium carbonate, extracted with ether, dried with sodium sulfate and distilled in vacuum. There was obtained 72 g 2-methyl-5-dimethylamino-1-hexen-3-one (IV) as a liquid which turned yellow on standing and had a characteristic amine odor. B.p. 78-80° at 6 mm.

n_D^{20} 1.4560; d_4^{20} 0.8909; MR_D 47.30; calculated 47.24.

4.200 mg substance: 0.330 ml N_2 (20°, 740 mm). 2.444 mg substance: 0.195 ml N_2 (20°, 740 mm). Found %: N 8.91, 9.05. $C_9H_{17}ON$. Calculated %: N 9.03.

The picrate formed flat needles with m.p. 119-120° (from alcohol). From the neutral products was isolated 2.7 g of a substance with m.p. 77-81° at 5 mm; n_D^{20} 1.4335.

b) To 10 g allylisopropenyl ketone (I) (b.p. 80-84° at 80 mm; n_D^{20} 1.4710) [1] was added 23 g 33% aqueous dimethylamine solution (heat was developed and the temperature rose to 61°). The mixture was then heated in a glass tube at 65° for 4 hours and then worked up as in the preceding experiment. The ethereal solution of organic bases was dried with magnesium sulfate and the product distilled in vacuum. 7.5 g of the above-described 2-methyl-5-dimethylamino-1-hexen-3-one (IV) was obtained. B.p. 98-100° at 14 mm; n_D^{20} 1.4560. The picrate melted at 119-120° (from alcohol).

c) A mixture of 30 g 1,5-dimethoxy-2-methylhexan-3-one (III) (b.p. 90-92° at 10 mm; n_D^{20} 1.4300) [1] and 60 g aqueous dimethylamine solution (33%) was heated in a sealed tube for 1.5 hours at 70° and the product worked up as in experiment a). The ethereal solution of the organic bases was dried with magnesium sulfate and distilled in vacuum. 16.2 g of 2-methyl-5-dimethylamino-1-hexen-3-one (IV) was obtained. B.p. 79-81° at 7 mm; n_D^{20} 1.4563.

The picrate melted at 119-120° and did not cause a depression in admixture with the preceding specimen.

Preparation of 1-methoxy-2-methyl-5-dimethylaminohexan-3-one (VII). A mixture of 40 g, 1,5-dimethoxy-2-methylhexan-3-one (III) and 20 ml dioxan, cooled to 0°, was saturated with gaseous dimethylamine (20 g increase in weight). The mixture was then heated in a glass tube for 4 hours at 100° and then worked up as in the first experiment. 15.7 g of 1-methoxy-2-methyl-5-dimethylaminohexan-3-one (VII) was obtained in the form of a colorless liquid with a faint odor; b.p. 89-92° at 7 mm.

n_D^{20} 1.4420; d_4^{20} 0.9151; MR_D 54.10; calculated 53.96.

8.07 mg substance: 19;03 mg CO_2; 8.02 mg H_2O. 10.03 mg substance: 23.69 mg CO_2; 10.08 mg H_2O. Found %: C 64.43, 64.46; H 11.12, 11.25. $C_{10}H_{21}O_2N$. Calculated %: C 64.26; H 11.29.

This amino ketone does not give a picrate. From the neutral products was isolated 15 g of the original ketone with b.p. 84-87° at 6 mm; n_D^{20} 1.4320.

Preparation of 2-methyl-5-dimethylaminohexan-3-one (V). a) 10 g of the freshly distilled unsaturated amino ketone (IV) in solution in 20 ml ethanol was hydrogenated in presence of Pt-catalyst. The amount of hydrogen absorbed was 1.5 l (one molecule). 5.4 g of 2-methyl-5-dimethylaminohexan-3-one (V) was obtained in the form of a mobile liquid with an amine-like odor, turning yellow on standing. B.p. 70-72° at 12 mm.

n_D^{20} 1.4300; d_4^{20} 0.8537; MR_D 47.72; calculated 47.60.

4.225 mg substance: 0.340 ml N_2 (23°, 744 mm). 6.450 mg substance: 0.505 ml N_2 (22°, 749 mm). Found %: N 9.08, 8.96. $C_9H_{19}ON$. Calculated %: N 8.99.

Its picrate melts at 109-110° (from alcohol).

b) 14 g 2-methyl-5-methoxyhexan-3-one (VI) (b.p. 163-166° at 722 mm; n_D^{20} 1.4208) [1] and 35 g 33% aqueous dimethylamine solution were heated in a glass tube for 4 hours at 70°. The excess of dimethylamine was distilled off in vacuum on a water bath at 45°. The solution was treated with hydrochloric acid until weakly acid, the neutral products were extracted with ether (the amount of neutral products was extremely small). The organic base was salted out with potassium carbonate, extracted with ether, dried with sodium sulfate and fractionated in vacuum. 5.3 g of the above-described 2-methyl-5-dimethylaminohexan-3-one (V) was obtained. B.p. 73-75° at 14 mm; n_D^{20} 1.4301.

The picrate of this amino ketone melted at 108-110° and did not depress the melting point of the preceding specimen.

Preparation of 2-methyl-5-N-piperidyl-1-hexen-3-one (VIII). a) To 142 g 2-methyl-5-methoxy-1-hexen-3-one (II) was added 140 g piperidine and 40 g water. After addition of the water the temperature rose to 45°. The mixture was heated at 100° for 11 hours and then worked up as in previous experiments. 98 g 2-methyl-5-N-piperidyl-1-hexen-3-one (VIII) was obtained. B.p. 111-112° at 5 mm.

n_D^{20} 1.4810; d_4^{20} 0.9396; MR_D 59.08; calculated 58.91.

6.500 mg substance: 0.412 ml N_2 (23°, 769 mm). 4.804 mg substance: 0.304 ml N_2 (23°, 769 mm). Found %: N 7.40, 7.39. $C_{12}H_{21}ON$. Calculated %: N 7.18.

This amino ketone does not form a picrate.

b) To 18 g allylisopropenyl ketone (I) was added 35 g piperidine. The temperature of the reaction mass rose to 70°. After adding the piperidine the mixture was heated in a sealed tube for 4 hours at 70°, and then fractionated in vacuum to give 19 g amino ketone (VIII). B.p. 115-118° at 7 mm; n_D^{20} 1.4810.

c) 10 g 1,5-dimethoxy-5-methylhexan-3-one (III), 10 g piperidine and 5 ml water were heated for 2.5 hours at 100°. Unreacted piperidine (5.3 g) was distilled off in a low vacuum and the reaction mass worked up as in previous experiments. 5.2 g of the amino ketone (VIII) was obtained. B.p. 110-113° at 4 mm; n_D^{20} 1.4810.

Hydrogenation of 2-methyl-5-N-piperidyl-1-hexen-4-one. 10 g freshly distilled amino ketone (VIII) was hydrogenated in 15 ml alcohol with Pt-catalyst and absorbed 1.38 l of hydrogen (the theoretical amount). 6.7 g of 2-methyl-5-N-piperidylhexan-3-one (IX) was obtained. B.p. 79-80° at 9 mm.

n_D^{20} 1.4550; d_4^{20} 0.9004; MR_D 59.60; calculated 59.41.

4.04 mg substance: 0.285 ml N_2 (21°, 745 mm). 4.700 mg substance: 0.314 ml N_2 (21°, 740 mm). Found %: N 7.36, 7.18. $C_{12}H_{23}ON$. Calculated %: N 7.10.

This amino ketone does not form a picrate.

Preparation of 2-methyl-6-dimethylamino-2-hexen-4-one (XI). 50 g 2-methyl-6-methoxy-2-hexen-4-one (X) (b.p. 93-95° at 20 mm; n_D^{20} 1.4531) [2] and 75 g 33% aqueous dimethylamine solution were heated in an autoclave for 1 hour at 65°. The excess of dimethylamine was distilled off in vacuum on the water bath at 45°. The reaction mass was acidified with hydrochloric acid, extracted with ether, dried with sodium sulfate and distilled in vacuum to give 25 g of 2-methyl-6-dimethylamino-2-hexen-4-one (XI). B.p. 87-89° at 12 mm.

n_D^{20} 1.4600; d_4^{20} 0.9035; MR_D 47.00; calculated 47.24.

3.260 mg substance: 0.249 ml N_2 (20°, 734 mm). 2.950 mg substance: 0.229 ml N_2 (18°, 731 mm). Found %: N 8.56, 8.76. $C_9H_{17}ON$. Calculated %: N 8.99.

The picrate of the amino ketone (XI) melted at 106-107° (from alcohol). More prolonged heating lowers the yield of amino ketone (XI) and a considerable amount of a volatile mixture of products was obtained which was not further examined.

Preparation of 2-methyl-6-dimethylaminohexan-4-one (XII). a) 5.5 g freshly distilled unsaturated amino ketone (XI) in solution in 15 ml alcohol was hydrogenated in presence of Pt-catalyst when 883 ml hydrogen was absorbed (theory requires 878 ml). The catalyst was filtered off, the alcohol distilled off and the residue fractionated in vacuum to give 4.1 g 2-methyl-6-dimethyl-aminohexan-4-one (XII). B.p. 79-80° at 13 mm.

n_D^{20} 1.4318; d_4^{20} 0.8573; MR_D 47.71, 47.52.

4.110 mg substance: 0.326 ml N_2 (19°, 731). 5.595 mg substance: 0.431 ml N_2 (17°, 733). Found %: N 8.92, 8.74. $C_9H_{19}ON$. Calculated %: N 9.03.

The picrate forms flat needles melting at 99-100° (from alcohol).

b) 50 g 2-methyl-6-methoxyhexan-4-one (XIII) (b.p. 64° at 1[illegible] mm; n_D^{20} 1.4190) [2] and 78 g 33% aqueous dimethylamine solution were heated in an autoclave at 70° for 5 hours. The excess dimethylamine solution was heated in an autoclave at 70° for 5 hours. The solution was acidified with hydrochloric acid until weakly acid and the neutral products were extracted with ether. [illegible]

The organic bases were salted out with potassium carbonate, extracted with ether, dried with sodium sulfate and distilled in vacuum to give 24.2 g of amino ketone(XII). B.p. 83-84° at 14 mm; n_D^{20} 1.4315. Its picrate melts at 99-100° and does not depress the melting point of the preceding specimen.

10 g of the original methoxy ketone (XIII) was recovered from the neutral products. B.p. 64-65° at 11 mm; n_D^{20} 1.4201.

Preparation of 1,5-bis-dimethylaminohexan-3-one (XVI). 20 g of a mixture of the methoxy ketones (XIV) and (XV) (b.p. 83-87° at 9 mm; n_D^{20} 1.4330) [9] and 50 g 33% aqueous dimethylamine solution was heated at 60° for 3 hours. The excess of dimethylamine was then distilled off in vacuum on a water bath at 45°. The organic bases were salted out with potassium carbonate, extracted with ether, dried with sodium sulfate, and distilled in vacuum to give 14.1 g 1,5-bis-dimethyl-aminohexan-3-one (XVI). B.p. 100-102° at 13 mm.

n_D^{20} 1.4563 d_4^{20} 0.9008; MR_D 56.30; calculated 56.26.

8.78 mg substance: 1.133 ml (20°, 753 mm). 4.79 mg substance: 0.615 ml (20°, 754 mm). Found %: N 14.90, 14.85. $C_{10}H_{22}ON_2$. Calculated %: N 15.05.

The picrate of the diamino ketone (XVI) melts at 145-146° (from alcohol).

Preparation of 1,5-bis-N-piperidylhexan-3-one (XVII). A mixture of 30 g methoxy ketones (XIV) and (XV) (b.p. 83-87° at 9 mm; n_D^{20} 1.4330 [10], 30 g piperidine and 10 g water was heated to 47° for 35 minutes. The product was then transferred to a glass ampoule and heated for 5 hours at 70°. The product was worked up as previously to give 25.3 g 1,5-bis-N-piperidylhexan-3-one (XVII). B.p. 98-100° at 4 mm.

n_D^{20} 1.4800; d_4^{20} 0.9537; MR_D 79.52; calculated 79.58.

2.563 mg substance: 0.235 ml N_2 (19.5°, 746 mm). 3.175 mg substance: 0.295 ml N_2 (19.5°, 746 mm). Found %: N 10.50, 10.64. $C_{16}H_{30}ON_2$. Calculated %: N 10.52.

The picrate of the diamino ketone (XVII), prepared by mixing with a saturated alcoholic solution of picric acid, melts at 134-135°.

3-Methyl-6-N-piperidyl-2-hepten-4-one (XXI). A mixture of 20 g 2-methoxy-5-methyl-5-hepten-3-one (XVIII) (B.p. 79-83° at 8 mm; n_D^{20} 1.4550) [10], 5 ml water and 20 g piperidine was heated in a sealed tube for 2.5 hours at 70°. The product was worked up as previously to give 8.2 g 3-methyl-6-N-piperidyl-2-hepten-4-one (XXI). B.p. 106-108° at 2 mm.

n_D^{20} 1.4830; d_4^{20} 0.9394; MR_D 63.63; calculated 63.51.

3.130 mg substance: 0.184 ml N_2 (20°, 748). 3.285 mg substance: 0.9052 ml N_2 (21°, 747).
Found %: N 6.74, 6.78. $C_{13}H_{23}ON$. Calculated %: N 6.70.

This amino ketone does not form a picrate. From the neutral products was recovered 11.3 g methoxy ketone (XVIII). B.p. 67-80° at 8 mm; n_D^{18} 1.4730.

Hydrogenation of 3-methyl-6-N-piperidyl-2-hexen-4-one. 2.5 g of the freshly distilled amino ketone (XXI) dissolved in 15 ml alcohol was hydrogenated with Pt-catalyst and took up 300 ml hydrogen (as against the 280 ml required by theory). The catalyst was filtered off, the alcohol distilled off, and the product twice fractionated in vacuum to yield 1.2 g 3-methyl-6-N-piperidylheptan-4-one (XXII). B.p. 88-90° at 2 mm.

n_D^{20} 1.4704; d_4^{20} 0.9248; MR_D 63.69; calculated 63.98.

1.955 mg substance: 0.115 ml N_2 (21° 737 mm). 2.615 mg substance: 0.115 ml N_2 (21°, 734 mm).
Found %: N 6.58, 6.43. $C_{13}H_{25}ON$. Calculated %: N 6.63.

The picrate came down as an oil which did not crystallize.

3-Methyl-6-dimethylamino-2-hepten-4-one (XIX). 18 g 2-methyoxy-5-methyl-5-hepten-3-one (XVIII). (B.p. 79-83° at 8 mm; n_D^{20} 1.4600) [10] and 40 g 33% aqueous dimethylamine solution were heated in an autoclave for 1.5 hours at 70°. After the usual treatment, the ethereal solution of the organic base was dried with sodium sulfate and distilled in vacuum. There was obtained 5.5 g of 3-methyl-6-dimethylamino-2-hepten-4-one (XIX). B.p. 70-72° at 4 mm.

n_D^{20} 1.4610; d_4^{20} 0.8982; MR_D 51.65; calculated 51.86.

13.17 mg substance: 3.76 ml 0.02 N $Na_2S_2O_3$. 20.78 mg substance: 6.05 ml 0.02 N $Na_2S_2O_3$.
Found %: N 7.99, 8.01. $C_{10}H_{19}ON$. Calculated %: N 8.28

The picrate came down as an oil from various solvents and did not crystallize

Hydrogenation of 3-methyl-6-dimethylamino-2-hepten-4-one. 2.5 g of the freshly distilled amino ketone (XIX) in solution in 15 ml alcohol was hydrogenated in presence of Pt-catalyst for 9 hours, 300 ml hydrogen being taken up instead of the 330 ml theoretically required. The catalyst was filtered off, the alcohol distilled off and the residue fractionated in vacuum to give 1.2 g 3-methyl-6-dimethylamino-heptan-4-one (XX) with b.p. 62-64° at 2 mm.

n_D^{20} 1.4450; d_4^{20} 0.8731; MR_D 52.13; calculated 52.33

3.910 mg substance: 0.205 ml N_2 (16°, 763 mm). 4.870 mg substance: 0.318 ml N_2 (20°, 751 mm).
Found %: N 7.73, 7.52. $C_{10}H_{21}ON$. Calculated %: N 8.17.

This amino ketone does not form a picrate.

Preparation of cyclohexenyl-β-dimethylaminopropyl ketone (XXIV). a) 14 g allyl-Δ^1-cyclohexenyl ketone (b.p. 93-96° at 4 mm; n_D^{20} 1.5091) [11] and 50 g 33 % aqueous dimethylamine were energetically stirred at 70° for 4.5 hours (the initially homogeneous solution formed layers when heated). The excess of dimethylamine was removed in a vacuum on the water bath at 45°.

The solution was acidified with hydrochloric acid until acid, and the neutral products extracted with ether. The organic bases were salted out with potassium carbonate, extracted with ether, dried with sodium sulfate and distilled in vacuum to give 10 g Δ^1-cyclohexenyl-β-dimethylaminopropyl ketone (XXIV) in the form of a colorless liquid with a characteristic amine odor. B.p. 110-111° at 3 mm; n_D^{20} 1.5050; d_4^{20} 0.9664; MR_D 59.85; calculated 58.89.
The picrate of this amino ketone is a fine yellow powder. M.p. 163-164° (from alcohol).

8.30 mg substance: 3.90 ml 0.02 N $Na_2S_2O_3$. 7.50 mg substance: 3.54 ml 0.02 N $Na_2S_2O_3$. Found %: N 13.15, 13.21. $C_{18}H_{24}O_8N_4$. Calculated %: N 13.21.

b) 20 g β-methoxypropyl-Δ'-cyclohexenyl ketone (XXIII) (b.p. 102-104° at 4 mm; n_D^{20} 1.4870) [11] and 50 g 33% aqueous dimethylamine were heated in a glass tube for 3 hours at 70°. The reaction mixture was worked up as in the preceding experiment to give 10.3 g cyclohexenyl-β-dimethylaminopropyl ketone (XXIV) with b.p. 110-111° at 3 mm; n_D^{20} 1.5050. The picrate melted at 163-164° and did not depress the melting point of the previous sample. 7 g of the methoxy ketone (XXIII) was recovered from the neutral products. B.p. 100-103° at 3 mm; n_D^{20} 1.4863.

Hydrogenation of cyclohexenyl-β-dimethylaminopropyl ketone. 4.2 g of the freshly distilled amino ketone (XXIV) in solution in 20 ml alcohol was hydrogenated with Pt-catalyst. 575 ml hydrogen (550 ml is required by theory) was absorbed in the course of 8 hours, giving 1.3 g cyclohexyl-β-dimethylaminopropyl ketone (XXV) in the form of a transparent liquid with a faint amine odor. B.p. 80-82° at 2 mm.

n_D^{20} 1.4810; d_4^{20} 0.9453; MR_D 59.33; calculated 59.41.

3.216 mg substance: 0.204 ml N_2 (22°, 755 mm). 2.806 mg substance: 0.167 ml N_2 (23°, 750 mm). Found %: N 7.28, 6.77. $C_{12}H_{23}ON$. Calculated %: N 7.10.

This amino ketone does not give a picrate.

Cyclohexenyl-β-(N-piperidyl)-propyl ketone (XXVI). 20 g β-methoxypropylcyclohexenyl ketone (XXIII) (b.p. 102-104° at 4 mm; n_D^{20} 1.4870) [11] 5 ml water and 15 g piperidine were heated at 100° for 3 hours. The reaction mixture was then worked up in the usual way to give 12.3 g Δ'-cyclohexenyl-β-(N-piperidyl)-propyl ketone (XXVI) in the form of a thick liquid with b.p. 114-116° at 4 mm; n_D^{20} 1.5150. Its picrate forms fine golden needles melting at 118-119° (from alcohol).

6.595 mg substance: 0.706 ml N_2 (23°, 747 mm). 9.172 mg substance: 0.961 ml N_2 (22°, 745 mm). Found %: N 12.14, 11.89. $C_{21}H_{28}O_8N_4$. Calculated %: N 12.07.

SUMMARY

An aqueous solution of dimethylamine acts on allylisopropenyl ketone (I) and the methoxy ketones (II, III) to form, in good yield, the amino ketone (IV), which takes up one molecule of hydrogen when hydrogenated and gives the saturated amino ketone (IV). This amino ketone is also obtained by the action of dimethylamine on the saturated methoxy ketone (VI). Anhydrous dimethylamine reacts with the dimethoxy ketone (III) to give the methoxyamino ketone (VII).

Aqueous solutions of piperidine act on the dienone (I) and the methoxy ketones (II, III) to form the amino ketone (VIII), which absorbs one molecule of hydrogen on hydrogenation and forms the saturated amino ketone (IX).

Dimethylamine reacts with the methoxy ketone (X) to give a good yield of the amino ketone (XI), which absorbs one molecule of hydrogen when hydrogenated and forms the saturated amino ketone (XII); the latter is also obtained by the action of dimethylamine on the saturated methoxy ketone (XIII).

Reaction of dimethylamine with the methoxy ketones (XIV, XV) gives the diaminoketone (XVI), and with piperidine the same methoxy ketones give the diaminoketone (XVII).

Dimethylamine acts on the methoxy ketone (XVIII) to form the amino ketone (XIX), which on hydrogenation forms the saturated amino ketone (XX). Piperidine reacts with the methoxy ketone (XVIII) to form the amino ketone (XXI), which on hydrogenation forms the saturated amino ketone (XXII).

Dimethylamine acts on the methoxy ketone (XXIII) to give the amino ketone (XXIV), which hydrogenates to the saturated amino ketone (XXV), while piperidine with the methoxy ketone (XXIII) gives the amino ketone (XXVI).

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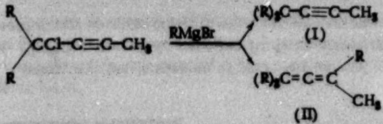
INTRAMOLECULAR REARRANGEMENTS IN THE ACETYLENE SERIES

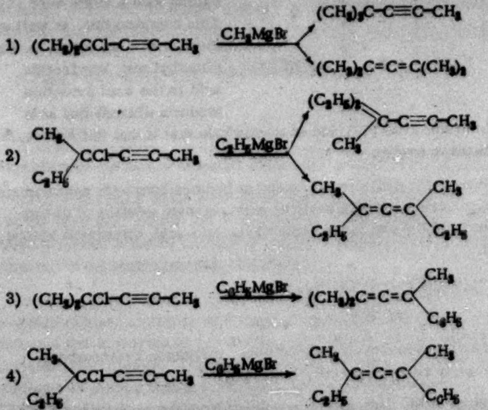
VII. REACTION OF 2,2,3-TRIMETHYL-3-CHLOROHEXYNE-4 WITH ORGANOMAGNESIUM COMPOUNDS

A. I. Zakharova and R. A. Sapozhnikova

In previous communications [1,2] on the study of the interaction of acetylenic tertiary chlorides of the type of $(R)_2CCl{-}C{\equiv}C{-}CH_3$ with organomagnesium compounds it was pointed out by one of us that the reaction is complex and that its products, apart from the corresponding acetylenic hydrocarbons with a quaternary carbon atom (I), are isomeric hydrocarbons with an allene structure (II):



It was also established that the direction of the reaction was influenced by the character of the organomagnesium compound. In the reaction of acetylenic chlorides with RMgBr (where R = CH_3 or C_2H_5) there is formed a mixture of two hydrocarbons: an acetylenic one (I), the product of normal substitution of chlorine for the radical of the organomagnesium compound, and an allenic one (II), whose formation is only possible when intramolecular rearrangement takes place in the instant of reaction (equations 1 and 2). In the case, however, of reaction of the chloride with C_6H_5MgBr the reaction proceeds exclusively in the second direction with formation only of a tetrasubstituted allenic hydrocarbon (equations 3 and 4):



Continuing our investigations in this direction, we decided to examine other examples of this phenomenon. From this standpoint we performed reactions between an acetylenic tertiary chloride—2,2,3-trimethyl-3-chlorohexyne-4 (III) – and organomagnesium compounds (CH_3MgBr and C_6H_5MgBr). The reactions were conducted in the conditions described in previous papers [1,2]. After appropriate treatment of the reaction mass obtained by reaction of the chloride (III) with CH_3MgBr, a hydrocarbon whose physical constants are listed in Table 2 was obtained in 73% of the theoretical yield. The molecular weight and elementary analysis of the product correspond to the formula $C_{10}H_{18}$. It does not react with maleic anhydride. The Raman spectrum of this hydrocarbon was plotted. As Table 1 shows, the spectrum contains strong lines corresponding to the characteristic frequencies of the triple bond (2225 and 2261 cm^{-1}) and of the double bond (1638 cm^{-1}).

TABLE 1

Raman Spectrum of the Product of Interaction of the Chloride (III) with CH_3MgBr.

386 (1), 420 (2), 446 (2), 551 (2), 578 (2), 621 (5), 745 (3), 852 (3), 922 (4), 1028 (2), 1066 (2), 1132 (2), 1202 (2), 1230 (2), 1256 (2), 1383 (4), 1447 (4), 1603 (2), 1638 (4), 2225 (4), 2261 (3).

The presence in the spectrum of a line characteristic of compounds containing an acetylenic linkage pointed to formation of a product of the normal reaction – the acetylenic hydrocarbon 2,2,3,3-tetramethylhexyne-4 (IV), but on the other hand the spectrum clearly indicated that an acetylenic hydrocarbon was not the sole product.

The product was oxidized with alkaline permanganate with cooling. The oxidation did not quite proceed on the usual lines. At first it proceeded very readily, but later the solution became decolorized although less oxidizing agent had been consumed than was required by calculation.* Oxidation was stopped. Examination of the neutral products revealed the formation of acetone and pinacoline. This pointed to the presence in the investigated hydrocarbon mixture of a tetrasubstituted allene – 2,2,3,5-tetramethylhexadiene-3,4 (V). A minute amount of acetic acid was identified in the acidic products of oxidation.

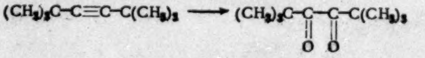
Apart from acetone and pinacoline, another product was isolated from the alkaline solution which proved on closer examination (molecular weight determination, elementary analysis) to be the hydrocarbon $C_{10}H_{18}$. Its composition therefore corresponded to the composition of the product subjected to oxidation, but it differed considerably in physicochemical properties (Table 2).

TABLE 2

Substance	Constants				
	B.p.	d_4^{20}	n_α^{20}	MR_α	Relative dispersion, $\omega_{\alpha\beta}$
Hydrocarbon mixture subjected to oxidation	47° at 15 mm	0.7794	1.4416	46.81	22.2
Hydrocarbon recovered from the oxidation products	50-51.5° at 25 mm	0.7932	1.4369	45.61	18.83

Particularly conspicuous is the sharp reduction in relative dispersion of the hydrocarbon recovered from the oxidation products; according to the literature the relative dispersion of 18.8 corresponds to a hydrocarbon with a triple bond [3]. This consideration, as well as the fact that we failed to find dimethyl tert. butylacetic acid in the acid oxidation products whereas this acid should be formed by oxidation of the acetylenic hydrocarbon (IV), led us to conclude that it was this hydrocarbon which was recovered since it was the more difficult to oxidize.

There is evidence in the literature pointing to the difficulty of oxidizing hydrocarbons with approximately the structure in question. Thus, for instance, in the oxidation with alkaline permanganate solution of di-tert-butylacetylene by Hennion and Banigan [4], instead of the anticipated trimethylacetic acid, ditertbutyl ketone was obtained, and no further oxidation occurred.



$$(CH_3)_3C-C\equiv C-C(CH_3)_3 \longrightarrow (CH_3)_3C-\underset{\displaystyle \overset{\|}{O}}{C}-\underset{\displaystyle \overset{\|}{O}}{C}-C(CH_3)_3$$

In this respect such hydrocarbons behave to some extent like disubstituted acetylenic hydrocarbons containing triphenylmethyl groups, which are known to be exceptionally stable [5].

Unfortunately, due to the very small amount of the hydrocarbon recovered from the oxidation products, we were unable conclusively to establish its structure. But all the data set out above point in all probability to the presence of an acetylenic hydrocarbon formed by the normal reaction of chloride (III) with CH_3MgBr. In this case, therefore, by sacrificing one of the hydrocarbons of the investigated mixture – the tetrasubstituted allene (V) which was oxidized to acetone and pinacoline – we were able to isolate the second hydrocarbon – the disubstituted acetylene (IV).

Thus, in this case also, we have been able to demonstrate that the reaction between tertiary acetylenic chlorides and organomagnesium compounds leads to formation of two hydrocarbons: The product of normal substitution, a disubstituted acetylene, and the product of an anomalous reaction, a tetrasubstituted allene.

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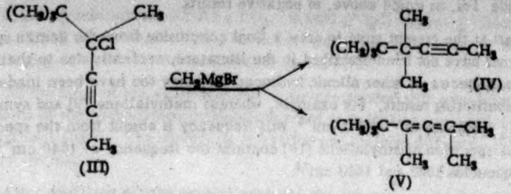
* The amount of oxidizing agent used was calculated on the assumption that the acetylenic and allenic hydrocarbons were present in equal amounts.



A study was also made of the reaction of chloride (III) with C_6H_5MgBr. This reaction gave a hydrocarbon whose elementary analysis and molecular weight corresponded to the formula $C_{15}H_{20}$. Oxidation with alkaline permanganate solution yielded pinacoline, acetophenone and a small amount of benzoic acid. The very same products were obtained by ozonolysis of the hydrocarbon.

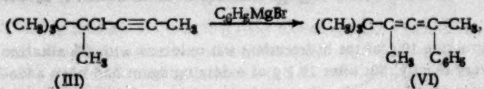
The Raman spectrum of this hydrocarbon was plotted. As shown in Table 3, the spectrum contains strong lines in the region of the characteristic frequencies 1604 and 1598 cm^{-1}. The doublet ~1600 cm^{-1} is evidence, as we know [6], of the presence of a benzene ring. No lines were observed in the region characteristic of the acetylenic bond.

TABLE 3

Raman Spectrum of the Product of Reaction of the Chloride (III) with C_6H_5MgBr.

400 (1), 550(1), 621 (1), 643 (1), 790 (1), 874 (1), 998 (5), 1028(1), 1154 (1), 1254 (1), 1274 (1), 1378 (0.5), 1444 (0.5) **1598** (5), **1604** (4).

The spectrographic data for the hydrocarbon in question permits the conclusion that it does not contain a a triple bond, while the formation during oxidation and ozonolysis of only pinacoline and acetophenone demonstrates that the reaction proceeds entirely with molecular rearrangement according to the scheme:



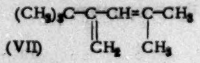
$$(CH_3)_3C-\underset{\substack{|\\CH_3}}{CCl}-C\equiv C-CH_3 \xrightarrow{C_6H_5MgBr} (CH_3)_3C-\underset{\substack{|\\CH_3}}{C}=C=\underset{\substack{|\\C_6H_5}}{C}-CH_3,$$

(III) (VI)

with formation of the tetrasubstituted allene, 2,2,3-trimethyl-5-phenylhexadiene-3,4 (VI).

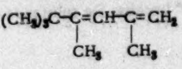
Thus it has once again been shown that the character of the organomagnesium compound influences the result of the reaction. Formation of the normal reaction products – disubstituted acetylenic hydrocarbons with a quaternary carbon atom of the type of (I) – is evidently hindered by steric hindrance when a phenyl radical is present in the organomagnesium compound.

In conclusion it must be noted that both in this investigation and in earlier ones [1,2] on the reaction of acetylenic tertiary chlorides with organomagnesium compounds as represented in equations 1-4, we have demonstrated the formation of acetylenic hydrocarbons with a quaternary carbon atom (I) both by the chemical and spectrographic method. On the other hand the formation in this reaction, side by side with acetylenic hydrocarbons, of allenic hydrocarbons (II), has only been chemically demonstrated, namely by the preparation of the corresponding ketones by oxidation and ozonolysis. There are no strong lines in the ~1070 cm^{-1} region of the Raman spectra of the investigated hydrocarbon mixtures, i.e. the region of frequencies characteristic of the allene linkage, according to the literature [7]. On the other hand in all cases strong lines characterizing the frequency of the double bond, i.e. ~1640 cm^{-1}, were observed. In this connection it may be suggested that the reaction products contain hydrocarbons with a conjugated system of double bonds. In the present investigation, for example, the appearance of acetone and pinacoline during oxidation of the product of reaction of chloride (III) with CH_3MgBr might be explained by the simultaneous presence of two hydrocarbons containing a conjugated system of double bonds (VII) and (VIII): *



$$(CH_3)_3C-\underset{\substack{\|\\CH_2}}{C}-CH=\underset{\substack{|\\CH_3}}{C}-CH_3$$

(VII)



$$(CH_3)_3C-\underset{\substack{|\\CH_3}}{C}=CH-\underset{\substack{|\\CH_3}}{C}=CH_2$$

(VIII)

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* This hypothesis is supported by the presence of acetic acid in the oxidation products.

These hydrocarbons could have been formed by subsequent isomerization of the initially formed allene hydrocarbon (V), but our attempts to demonstrate the presence of the latter by chemical methods, e.g., by forming condensation products with maleic anhydride, led, as stated above, to negative results.

On the other hand, it is still difficult at the present time to draw a final conclusion from the Raman spectra because the spectra of tetrasubstituted allenes have not been described in the literature, evidently due to their difficult availability. Concerning the Raman spectra of other allenic hydrocarbons, they too have been inadequately investigated and in some cases even with conflicting results. For example, whereas methylallene [9] and symm. dimethylallene [10] exhibit a characteristic frequency of $\sim$1071 cm^{-1}, this frequency is absent from the spectrum of asymm. dimethylallene [9]. Again, the spectrum of ethylallene [10] contains the frequency of 1640 cm^{-1} which is not inferior in intensity to the frequencies 1062 and 1098 cm^{-1}.

EXPERIMENTAL

The starting acetylenic chloride 2,2,3-trimethyl-3-chlorohexyne-4 was prepared by the action of hydrogen chloride on methyl-tert-butylmethylethinyl carbinol, which in turn was synthesized by the Favorsky reaction from pinacoline and methylacetylene. The constants of both substances corresponded to those enumerated in a paper by one of us and K. N. Dobromyslova [8].

1. Reaction of 2,2,3-trimethyl-3-chlorohexyne-4 with CH_3MgBr

The Grignard reagent was prepared from 12 g magnesium and 67 g methyl bromide in 150 ml ether. During the addition of the chloride (III) (44 g in 100 ml ether) the mixture was rapidly stirred and cooled with cold water. The complex was left overnight and then decomposed with 6% hydrochloric acid solution with external cooling to 0°. The ethereal solution was dried with $MgSO_4$, the ether driven off, and the residue fractionated in vacuum to give the following fractions: 1) B.p. 47° at 15 mm; 2) b.p. 47-53° at 15 mm. The yield of the first fraction was 73%. The prepared hydrocarbon was a colorless, transparent liquid.

d_4^0 0.7953; d_4^{20} 0.7794; n_α^{20} 1.4416; n_β^{20} 1.45143; MR_α 46.81; MR_β 47.71. $C_{10}H_{18}|^{\equiv}$. Calculated MR_α 46.11; MR_β 46.95. $C_{10}H_{18}|^{=}_{2}$. Calculated MR_α 47.15; MR_β 48.09. Relative dispersion $\omega_{\alpha\beta}$ 22.2.

0.3418 g substance: 22.27 g benzene: Δt 0.57°. 0.1517 g substance; 22.27 g benzene: Δt 0.25°. 0.0710 g substance: 0.2253 g CO_2; 0.0826 g H_2O. 0.0673 g substance: 0.2140 g CO_2; 0.0771 g H_2O. Found %: C 86.54, 86.72; H 13.01, 12.82; M 134.6, 136.2. $C_{10}H_{18}$. Calculated %: C 86.96; H 13.04; M 138.

Oxidation. In order to investigate the structure 10 g of the hydrocarbon was oxidized with 1% alkaline $KMnO_4$ solution. Oxidation at first proceeded very readily, but after 19.1 g of oxidizing agent had been added the solution became colorless. The calculated requirement for complete oxidation of 10 g of the mixture of hydrocarbons was 26.7 g $KMnO_4$. The alkaline solution together with the manganese dioxide precipitate was transferred to a flask for distillation of the neutral products. The liquid in the receiver separated into two layers: an upper one of greenish liquid and a lower aqueous layer. The latter was separated and again distilled. The first drops of distillate were collected in a solution of p-nitrophenylhydrazine acetate. A precipitate came down which after recrystallization from methanol had m.p. 146-148° and did not depress the melting point of authentic acetone p-nitrophenylhydrazone.

0.0465 g substance: 8.8 ml N_2 (20°, 759.4 mm). 0.0384 g substance: 7.4 ml N_2 (20°, 751.5 mm). Found %: N 21.72, 21.87. $C_9H_{11}O_2N_3$. Calculated %: N 21.76.

The upper layer (about 2 g) was distilled into a solution of semicarbazide acetate. A precipitate formed and a layer of greenish liquid again collected in the mother liquor. The precipitate was recrystallized from methanol and had m.p. 156°. It did not depress the melting point of pinacoline semicarbazone.

0.0502 g substance: 11.5 ml N_2 (19°, 753.7 mm). 0.0552 g substance: 12.4 ml N_2 (18°, 770.4 mm). Found %: N 26.23, 26.36. $C_7H_{15}ON_3$. Calculated %: N 26.75.

The layer of greenish liquid was separated from the semicarbazide mother liquor, dried over $MgSO_4$ and distilled. A fraction boiling at 50-51.5° at 25 mm was collected. Since the liquid was colored, it was transferred to a bulb for further purification. The air was removed from the bulb which was then sealed, and the liquid was subjected to molecular distillation to give a transparent liquid with a faint yellow-green tint. It was impossible to determine its specific gravity at 0° because the substance crystallized at this temperature.

d_4^{20} 0.7932; n_α^{20} 1.43696; n_β^{20} 1.44519; MR_α 45.61; MR_β 46.35. $C_{10}H_{18}\text{F}$. Calculated MR_α 46.11; MR_β 46.95. Relative dispersion $\omega_{\alpha\beta}$ 18.83.

0.1240 g substance: 0.3958 g CO_2: 0.1421 g H_2O. 0.0610 g substance; 19.85 g benzene: Δt 0.115°. 0.1296 g substance: 17.25 g benzene: Δt 0.275°. Found %: C 87.05; H 12.82; M 133.6, 136.6. $C_{10}H_{18}$. Calculated %: C 86.96; H 13.04; M 138.

On the basis of the analytical results we can assume with a high degree of probability that one of the components of the hydrocarbon mixture subjected to oxidation was unaffected by the oxidizing agent and was recovered unchanged. The molecular refraction and relative dispersion indicated that this hydrocarbon was an acetylene derivative.

After distilling off the neutral products, the precipitate of manganese dioxide was filtered off, and the solution concentrated prior to acidification with sulfuric acid. Several fractions of 15 ml each were collected on distilling the volatile acids. Silver salts were prepared by treatment with silver carbonate and were identified as silver acetate.

0.0833 g substance: 0.0536 g Ag. 0.0222 g substance: 0.0143 g Ag. Found %: Ag 64.34, 64.40. $C_2H_3O_2Ag$. Calculated %: Ag 64.67.

2. Reaction of 2,2,3-Trimethyl-3-chlorohexyne-4 (III) with C_6H_5MgBr

The organomagnesium compound prepared from 9 g magnesium and 55 g bromobenzene in 200 ml ether was decanted from the magnesium residue and to it was added dropwise, with rapid stirring, 44.5 g chloride (III) (0.35 mole) in 100 ml ether. The reaction proceeded quietly. After the whole of the chloride had been added, the solution was stirred for another 2 hours with heating on the water bath (40°). On the following day the complex was decomposed with 6% hydrochloric acid while being stirred and externally cooled to 0°. The ethereal solution was dried with $MgSO_4$. Fractionation of the reaction product over metallic sodium yielded two fractions: 1) B.p. 56-60° at 30-34 mm; 2) b.p. 118-119° at 10 mm. Due to its very small quantity the first fraction was not investigated. The second fraction was redistilled to give a hydrocarbon with b.p. 111-112° at 6 mm. Yield 36% of theory.

d_4^{0} 0.9265; d_4^{20} 0.9101; n_D^{20} 1.53353; n_α^{20} 1.53060; n_β^{20} 1.54968; MR_D 68.49; MR_α 67.92; MR_β 69.97. $C_{15}H_{20}\text{F}_8$. Calculated MR_D 66.93; MR_α 66.48; MR_β 67.99.

0.0955 g substance: 0.3135 g CO_2; 0.0846 g H_2O. 0.0814 g substance: 0.2673 g CO_2; 0.0731 g H_2O. 0.1098 g substance; 17.4 g benzene: Δt 0.16°. 0.3178 g substance; 17.55 g benzene: Δt 0.46°. Found %: C 89.52, 89.65; H 9.90, 10.05; M 197.1, 196.8. $C_{15}H_{20}$. Calculated %: C 90.0; H 10.0, M 200.

Ozonization. 3.3 g of the hydrocarbon was ozonized in chloroform solution until ozone absorption had ceased. The chloroform was removed in vacuum and the ozonides decomposed by boiling with water. The odor of pinacoline was detected on distilling the first drops of the neutral ozonolysis products with steam, but we were unable to isolate the substance owing to the small quantity. The oil which collected in the receiver was separated from water and dried; it was then treated with a solution of semicarbazide acetate when a precipitate came down which after recrystallization melted at 197-198° and did not depress the melting point of acetophenone semicarbazone.

0.0908 g substance: 18.7 ml N_2 (19°, 764.5 mm). Found %: N 23.88. $C_9H_{11}ON_3$. Calculated %: N 23.73.

The solution remaining after distillation of the neutral products was acidified with sulfuric acid. On distillation of the acid products, white crystals were collected which after drying and sublimation melted at 119-120° and did not depress the melting point of benzoic acid. No other acids were detected.

Oxidation. 6.25 g of the hydrocarbon was taken for oxidation. This was performed with 1% alkaline solution of $KMnO_4$ in amount calculated for the expenditure of 4 atoms of oxygen per molecule of hydrocarbon. A two-layer liquid was collected on distilling the neutral products of oxidation. The top layer (a yellow oil) was separated from the water and distilled into a solution of semicarbazide acetate. The first drops, b.p. 105-110°, were collected separately. Semicarbazones were prepared from each fraction. The semicarbazone of the first fraction melted at 154-156° (from methanol) and did not depress the melting point of pinacoline semicarbazone.

0.0586 g substance: 13.6 ml N_2 (21°, 770.4 mm). Found %: N 26.91. $C_7H_{15}ON_3$. Calculated %: N 26.75.

The semicarbazone of the second fraction melted at 197-198° after recrystallization and did not depress the melting point of acetophenone semicarbazone.

0.0541 g substance: 11.1 ml N_2 (17.5°, 761.6 mm). Found %: N 23.90. $C_9H_{11}ON_3$. Calculated %: N 23.73.

The precipitate of manganese dioxide was filtered off after distillation of the neutral products and the solution was acidified with sulfuric acid and distilled. Crystals formed in the condenser and melted at 118-120° after drying and sublimation. They did not depress the melting point of benzoic acid.

SUMMARY

1. The reaction of the tertiary acetylenic chloride, 2,2,3-trimethyl-3-chlorohexyne-4 (III), with organomagnesium compounds was investigated.

2. It was shown that the reaction of chloride (III) with CH_3MgBr is accompanied by intramolecular rearrangement with the consequence that in addition to the normal reaction product – the disubstituted acetylenic hydrocarbon with a quaternary carbon atom, 2,2,3,3-tetramethylhexyne-4 (IV) – there is formed an anomalous reaction product in the shape of the tetrasubstituted allene, 2,2,3,5-tetramethylhexadiene-3,4 (V).

3. Reaction of the chloride (III) with C_6H_5MgBr only gave the anomalous product – the tetrasubstituted allene, 2,2,3-trimethyl-5-phenylhexadiene-3,4 (VI).

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* See Consultants Bureau translation, p. 1293.

** See Consultants Bureau translation, p. 2099.

CONDENSATION OF FORMALDEHYDE WITH KETONES AND ALDEHYDES

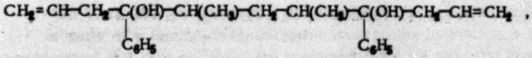
SYNTHESIS OF 5,7-DIMETHYL-4,8-DIPHENYLUNDECADIENE-1,10-DIOL-4,8

N. K. Astakhova and M. N. Tilichenko

In a recent communication [1] we described a convenient preparative synthesis of methylene-bis-propiophenone ($C_6H_5COCH(CH_3)CH_2CH(CH_3)COC_6H_5$), by condensation of propiophenone with formaldehyde. This delta-diketone is obtained in the form of a crystalline compound (in quantity of about one-third of the total mass of product) and in the form of a yellow syrup (about two-thirds). We suggested [1] that these were stereoisomers, the first probably being the inactive form and the second the racemate.

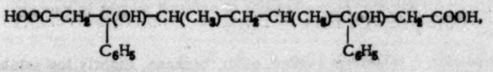
In the present paper we describe the reaction of the crystalline and liquid forms of methylene-bis-propiophenone with allyl iodide and magnesium by the Yavorsky method [2] as modified by Mazurevich [3].

The reaction with both the crystalline and the liquid methylene-bis-propiophenone gave a quantitative yield of



$$CH_2=CH-CH_2-\underset{\underset{C_6H_5}{|}}{C}(OH)-CH(CH_3)-CH_2-CH(CH_3)-\underset{\underset{C_6H_5}{|}}{C}(OH)-CH_2-CH=CH_2\ ,$$

5,7-dimethyl-4,8-diphenylundecadiene-1,10-diol-4,8, in the form of a semisolid syrup. Oxidation of the glycol gave a dibasic acid in the form of a white, amorphous powder,



$$HOOC-CH_2-\underset{\underset{C_6H_5}{|}}{C}(OH)-CH(CH_3)-CH_2-CH(CH_3)-\underset{\underset{C_6H_5}{|}}{C}(OH)-CH_2-COOH,$$

4,6-dimethyl-3,7-diphenyl-3,7-dihydroxynonane dicarboxylic acid, the structure of which was confirmed by analysis of its silver salt.

The first and second compounds each contain four asymmetric carbon atoms and they are consequently a mixture of several stereoisomeric forms (which evidently explains why at first we were unable to obtain them in crystalline form).

EXPERIMENTAL

The reaction with crystalline and liquid methylene-bis-propiophenone was performed in completely identical conditions: To 4.28 g (0.178 mole) freshly prepared magnesium turnings, covered with 75 ml absolute ether, was added about 2 ml freshly distilled allyl iodide (b.p. 99-103°), to "activate" the turnings, and the mixture heated on the water bath for 30-40 minutes. Addition was then made in small portions, with mechanical stirring, of 20 g (0.07 mole) diketone and 30 g (0.178 mole) allyl iodide dissolved in 40 ml absolute ether. The reaction flask was cooled the whole time with a cold-water bath, since the process proceeds too energetically without cooling, even with very slow addition of the reagents.

On the following day the reaction mass was treated first with aqueous ether, then with iced water and hydrochloric acid. The ether layer was separated and the aqueous layer extracted several times with fresh portions of ether. The ether extracts were combined with the ether layer and the whole washed with water until it gave a negative reaction for halogen. After drying with freshly calcined sodium sulfate, the ether was distilled off on the water bath and the flask residue brought to constant weight in a vacuum (1-2 mm) at 50-60°. The so-obtained product was a soft, vitreous mass (a thread-forming syrup) with the color of tea. In the reaction with the crystalline diketone the yield was 25.2 g or 97.8% of the theoretical; with the liquid diketone it was 24.63 g or 94.6%.

The substance distilled in vacuum (less than 1 mm) at 210-227° (with decomposition). With Deniges' reagent [4] it gives a characteristic precipitate, typical of compounds with double bonds and tertiary alcoholic groups. It is readily soluble in all common solvents except water. It has a pleasant mushroomy odor.

0.1131 g substance: 3420 g CO_2; 0.0953 g H_2O. 0.1198 g substance: 0.4259 g CO_2; 0.1132 g H_2O. 0.1218 g substance:* 0.3654 g CO_2; 0.0905 g H_2O. Found %: C 82.50, 81.94, 81.89; H 9.40, 9.05, 8.31. $C_{25}H_{32}O_2$. Calculated %: C 82.37; H 8.85. 0.2856 g substance; 16.63 g benzene: Δt 0.256°. 0.2660 g substance; 14.48 g benzene: Δt 0.267°. 0.2824 g substance: 16.37 g benzene; Δt 0.225°. Found: M 351.4, 360.7, 352.3. $C_{25}H_{32}O_2$. Calculated: M 364.5. Iodine value (McIlheny's method) 0.2714 g substance: 28.14 ml 0.1 N $Na_2S_2O_3$. 0.2366 g substance 24.00 ml 0.1 N $Na_2S_2O_3$. 0.2961 g substance* 32.28 ml 0.1 N $Na_2S_2O_3$. Found: iodine value 133.3, 132.7, 138.5. $C_{25}H_{32}O_2$. Calculated: iodine value 132.28. 0.1696 g substance: 22.5 ml CH_4 (22°, 750 mm) (Terentyev) 0.1853 g substance: 26.1 ml CH_4 (23°, 750 mm). 0.1525 g substance:* 20.5 ml CH_4 (19.5°, 746.5 mm). Found %: OH 9.01, 9.51, 9.20. $C_{25}H_{32}O_2$. Calculated %: OH 9.33.

Oxidation. Oxidation was effected by the method described by Chojn [5]. The amount of oxidizing agent used was calculated on the assumption that 1 mole of substance required 8 atoms of oxygen.

5 g unsaturated glycol was dissolved in 50 ml acetone, a little water was added and the whole thoroughly emulsified. To the emulsion, cooled in a bath containing iced water, was added with good stirring a 4% $KMnO_4$ solution (12.1 g in 290 ml water) in small portions, also cooled with cold water. Decolorization of the permanganate took place fairly quickly. After the whole of the permanganate had been added, the excess was reduced by careful addition of a small amount of formaldehyde. The mixture was filtered and the precipitate together with the filter was transferred to a conical flask and digested several times with fresh portions of water. The filtered liquors were combined with the main filtrate and evaporated in a moderate vacuum at 70-80° approximately to a volume of 120 ml. The concentrated solution was extracted several times with ether to remove the neutral products. The clear liquid left after the ether treatment was acidified with 10% hydrochloric acid; an emulsion was formed which deposited a yellow oil. The oil was extracted with ether several times. The ether extract was washed with water several times until it gave a negative reaction for chlorine and dried with freshly calcined sodium sulfate. The ether was driven off and the residue brought to constant weight in vacuum at 50-60°. Yield of acid 2.5 g or 45.6% of theory.

The acid, in the form of a faintly yellow powder, is soluble in alcohol, ether, benzene, slightly less soluble in carbon tetrachloride and carbon bisulfide, and completely insoluble in water and gasoline (b.p. 80-100°). M.p. 63-67°. The acid could not be obtained in the crystalline form.

Preparation and analysis of the Ag salt. The acid was dissolved in concentrated ammonia by heating (dissolution takes place very slowly in the cold; it is also slow in dilute ammonia). The solution was heated until the ammonia had been completely driven off, filtered from a small amount of brown flocculent suspension, and precipitated with concentrated silver nitrate solution. A white, curdy precipitate of the silver salt immediately came down. It was sucked dry on a glass filter, washed with alcohol and water until it had a negative reaction for silver ions, and dried to constant weight at 80° (at 90-100° it decomposes appreciably).

0.2766 g substance: 0.0970 g Ag. Found %: Ag 35.07. $C_{23}H_{26}O_6$. Calculated %: Ag 35.13.

SUMMARY

1. It is shown that methylene-bis-propiophenone is an excellent component for the organomagnesium synthesis.

In its reaction with allyl iodide and magnesium, the process proceeds normally to form, in quantitative yield, 5,7-dimethyl-4,8-diphenylundecadien-1,10-diol-4,8, not described in the literature.

Oxidation of the unsaturated glycol yielded 4,6-dimethyl-3,7-diphenyl-3,7-dihydroxynonane dicarboxylic acid, not described in the literature.

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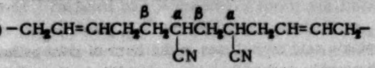
* Data for the same product obtained on the basis of the liquid methylene-bis-propiophenone.

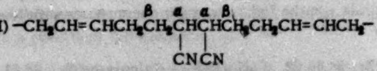
THE PROBLEM OF THE STRUCTURE OF THE COPOLYMER OF BUTADIENE AND ACRYLONITRILE

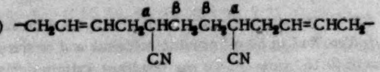
SYNTHESIS OF HEXANETETRACARBOXYLIC ACID

E. N. Alekseeva and V. D. Mezhov

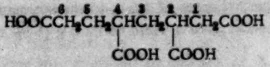
In 1939 one of the authors [1] published a paper on the elucidation of the structure of the copolymer of butadiene and acrylonitrile by the ozonization method. The main product of cleavage was isolated in the form of the trimethyl ester of 1,2,4-butanetricarboxylic acid. The properties of the free acid obtained by saponification of the trimethyl ester agreed completely with those of Ruzicka's preparation [2]. In addition to butantricarboxylic acid the ozonization products included a small amount of the tetramethyl ester of hexanetetracarboxylic acid whose structure could not be confirmed owing to the inadequate amount of material. The formation of hexanetetracarboxylic acid indicates that in the process of polymerization, apart from the regular successive alternation of molecules of butadiene and acrylonitrile, addition may take place between two molecules of acrylonitrile. There are three possible ways in which this addition could occur:

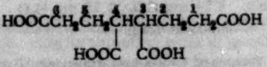
(I)

$-CH_2CH{=}CHCH_2\overset{\beta}{C}H_2\underset{CN}{\overset{\alpha}{C}}H\overset{\beta}{C}H_2\underset{CN}{\overset{\alpha}{C}}HCH_2CH{=}CHCH_2-$

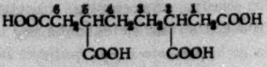
(II)

$-CH_2CH{=}CHCH_2\overset{\beta}{C}H_2\underset{CN}{\overset{\alpha}{C}}H\underset{CN}{\overset{\alpha}{C}}H\overset{\beta}{C}H_2CH_2CH{=}CHCH_2-$

(III)

$-CH_2CH{=}CHCH_2\underset{CN}{\overset{\alpha}{C}}H\overset{\beta}{C}H_2\overset{\beta}{C}H_2\underset{CN}{\overset{\alpha}{C}}HCH_2CH{=}CHCH_2-$

Oxidative cleavage could correspondingly yield three different hexanetetracarboxylic acids:

1)

$HOOC\overset{6}{C}H_2\overset{5}{C}H_2\underset{COOH}{\overset{4}{C}}H\overset{3}{C}H_2\underset{COOH}{\overset{2}{C}}H\overset{1}{C}H_2COOH$

2)

$HOOC\overset{6}{C}H_2\overset{5}{C}H_2\underset{HOOC}{\overset{4}{C}}H\underset{COOH}{\overset{3}{C}}H\overset{2}{C}H_2\overset{1}{C}H_2COOH$

3)

$HOOC\overset{6}{C}H_2\underset{COOH}{\overset{5}{C}}H\overset{4}{C}H_2\overset{3}{C}H_2\underset{COOH}{\overset{2}{C}}H\overset{1}{C}H_2COOH$

In order to establish which of the three possible hexanetetracarboxylic acids actually corresponds to the structure of the acid derived from the copolymer, all three isomers have been synthesized. Comparison of the properties of the acid isolated from the copolymer with those of the synthesized acids showed that it was identical with 1,2,4,6-hexanetetracarboxylic acid. Consequently in the successive addition of two molecules of acrylonitrile between themselves, the α-carbon atom of one molecule adds on to the β-carbon atom of the other (I).

A new original method was developed for preparation of the ester of β-bromopropionic acid used as intermediate. This method involved acting with dry hydrogen bromide on an alcoholic solution of acrylonitrile with intermediate formation of the hydrobromide of the imino ester.

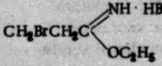
EXPERIMENTAL

All the condensation reactions were carried out in a three-necked flask equipped with a mechanical stirrer with a mercury seal, a dropping funnel and a reflux condenser topped by a calcium chloride tube. Sodium ethylate was first prepared and to this was added an ester with a mobile hydrogen atom. The reaction mixture was stirred for a short period, after which the second reaction component was added. At the end of the reaction the alcohol was distilled off under reduced pressure, the reaction mass was decomposed with water and extracted with ether, and the ether extract dried with calcium chloride. After distilling off the ether, the residue was fractionated in vacuum.

Preparation of the triethyl ester of 1,1,3-propanetricarboxylic acid. 8.74 g metallic sodium (0.38 g-atom) is dissolved in 95 ml absolute alcohol. To the solution of ethylate is added 61 g freshly dissolved ethyl maleate (0.38 mole). The resultant sodium ethyl malonate is cooled with ice and to it is added dropwise 50 g of the ethyl ester of β-bromopropionic acid (0.28 mole). The reaction mass is stirred for an hour at room temperature. After the treatment described above and fractionation under reduced pressure, the yield of triethyl ester of 1,1,3-propanetricarboxylic acid with b.p. 136° at 4 mm was 42 g (57.5%), and that of the tetraethyl ester of 1,3,3,5-pentanetetracarboxylic acid with b.p. 187° at 4 mm was 14 g (28%).

Synthesis of the ethyl ester of β-bromopropionic acid. 53 g acrylonitrile (1 mole) is dissolved in 150 ml ethyl alcohol (2.6 mole). Under ice cooling the solution is saturated with dry hydrogen bromide until the weight had increased to 160 g and the mass left overnight.

On the following day the hydrobromide of the imino ester of β-bromopropionic acid,



$CH_2BrCH_2C(=NH\cdot HBr)OC_2H_5$

, crystallized. After driving off the alcohol the amount of crystals increased. The crystalline mass was decomposed with water, the resultant colorless oil was distilled under reduced pressure. B.p. 64-65° at 5 mm. Yield 98-102 g (54-56 %).

The hydrobromide of the imino ester of β-bromopropionic acid crystallizes in the form of stout prisms; readily soluble in hot alcohol, sparingly soluble in cold. If thoroughly washed free of mother liquor, it may be kept for several days in the dark in a desiccator over calcium chloride. In the light it rapidly decomposes with loss of bromine.

0.1740 g substance: 13.25 ml 0.1 N $AgNO_3$. Found %: Br 60.92. $C_5H_{11}ONBr_2$. Calculated %: Br 61.30.

Preparation of 1,2,4,6-hexanetetracarboxylic acid. For the preparation of the ester of 1,2,4,4,6-hexanepentacarboxylic acid, 3.5 g metallic sodium (0.15 mole) is dissolved in 50 ml absolute alcohol and to the solution is added 39.5 g triethyl ester of 1,1,3-propanetricarboxylic acid (0.15 mole). To the resultant sodium derivative is added, with cooling, 28.6 g (0.09 mole) diethyl ester of 3-bromo-1,2-propanedicarboxylic acid prepared by the method of Anschutz and Reuter [3] from itaconic acid. After working up in the usual manner, an oil is obtained which is fractionated under reduced pressure. The boiling point of the pentaethyl ester of 1,2,4,4,6-hexanepentacarboxylic acid is 200-201° at 3 mm. A yellowish oil. A repeated fractionation gave a yield of 22.5 g (55% of theory).

0.3642 g substance: 0.7522 g CO_2; 0.2452 g H_2O. 4.00 mg substance: 8.24 mg CO_2; 2.75 mg H_2O. Found %: C 56.32, 56.17; H 7.47, 7.64. $C_{21}H_{34}O_{10}$. Calculated %: C 56.52; H 7.62.

The ester of 1,2,4,4,6-hexanepentacarboxylic acid is saponified by prolonged (16 hours) digestion with excess of a saturated solution of potassium hydroxide in methyl alcohol. The solution, after cooling, is acidified with excess hydrochloric acid and evaporated in vacuum at 70-80°. Water is added several times to the dry residue and evaporation in vacuum repeated.

The dry residue is pulverized in a mortar and extracted with dry acetone. From the acetone solution an oil is deposited with the help of benzene and partly crystallizes on standing. After several recrystallizations from acetone-benzene mixture and then from acetic acid, crystals are obtained with m.p. 158-163°, decomposing at 200°.

3.60 mg substance; 6.01 mg CO_2: 1.70 mg H_2O. 4.99 mg substance: 8.31 mg CO_2; 2.43 mg H_2O. Found %: C 45.53, 45.42; H 5.28, 5.32. $C_{10}H_{14}O_8$. Calculated %: C 45.80; H 5.35.

The acid is readily soluble in water, acetone and alcohol, sparingly in benzene.

Synthesis of 1,3,4,6-hexanetetracarboxylic acid. Silberrad [4] synthesized this acid by the action of β-iodopropionic acid ester on the disodium derivative of the tetraethyl ester of ethane tetracarboxylic acid followed by saponification of the condensation product. In the present investigation it was prepared by condensation of the sodium derivative of the triethyl ester of 1,1,3-propanetricarboxylic acid with diethyl α-bromoglutarate.

2.3 g metallic sodium (0.1 g-atom) is dissolved in 40 ml absolute alcohol, and to the solution is added 31.2 g of the triethyl ester of 1,1,3-propanetricarboxylic acid (0.12 mole). The solution is stirred at room temperature for an hour and addition is then made to it, with ice cooling, of 26.7 g (0.1 mole) diethyl α-bromoglutarate. After the cooled mixture had been stirred for 30 minutes, the alkalinity (to phenolphthalein) disappears and the solution is worked up as described previously. The boiling point of the pentaethyl ester of 1,3,4,4,6-hexanetetracarboxylic acid is 190° at 4 mm. Yield 11 g (24.6% of theory).

0.1214 g substance: 0.2510 g CO_2; 0.0817 g H_2O. 0.1335 g substance: 0.2759 g CO_2; 0.0899 g H_2O. Found %: C 56.46, 56.36; H 7.47, 7.48. $C_{21}H_{34}O_{10}$. Calculated %: C 56.50, H 7.62.

The ester is saponified by digestion (30 hours) with mechanical stirring with equal amounts by weight of concentrated hydrochloric acid and water. The solution is decolorized by heating with animal charcoal; after filtration it is then evaporated several times, using fresh portions of water, on the water bath. The residue crystallizes after standing for several days in a vacuum desiccator over sodium hydroxide. The dark, crystalline mass is recrystallized several times from acetone-benzene mixture. M.p. 216°.

0.1800 g substance: 0.3013 g CO_2; 0.0851 g H_2O. 0.2160 g substance: 0.3615 g CO_2; 0.1026 g H_2O. Found %: C 45.61, 45.63; H 5.25, 5.27. $C_{10}H_{14}O_8$. Calculated %: C 45.80; H 5.35.

Synthesis of 1,2,5,6-hexanetetracarboxylic acid. 3.5 g metallic sodium (0.15 mole) is dissolved in 75 ml absolute alcohol, and to the solution is added 26.9 g tetraethyl ester of 1,1,4,4-butanetetracarboxylic acid (0.075 mole) prepared by the method of Noyes and Kiriakidis [5]. The reaction mixture is heated for 15-20 minutes on the oil bath, and then addition is made of 31 g freshly distilled ethyl monochloroacetate (0.33 mole). Stirring and heating are continued up to the disappearance of the alkaline reaction (to phenolphthalein – about 15 hours), after which the reaction mixture is treated as usual. The boiling point of the hexaethyl ester of 1,2,2,5,5,6-hexanehexacarboxylic acid is 205-208° at 3 mm; the distillate crystallizes in the receiver, m.p. 52°. Yield 13.5 g (33.5% of the theoretical).

0.2230 g substance: 0.4542 g CO_2; 0.1552 g H_2O. 0.1882 g substance: 0.0742 g CO_2; 0.1272 g H_2O. Found %: C 55.56, 55.69; H 7.73, 7.71. $C_{24}H_{38}O_{12}$. Calculated %: C 55.59; H 7.34.

The ester is saponified and decarboxylated by prolonged digestion (35 hours) with equal amounts by weight of concentrated hydrochloric acid and water. After decolorization with animal charcoal the solution is evaporated on the water bath; water is added to the residue several times and evaporation to dryness is repeated. The dark, crystalline residue is recrystallized first from acetone-benzene, then from acetic acid and finally from water. M.p. 170-174°. Readily soluble in water, alcohol and acetone, sparingly in benzene and acetic acid.

3.39 mg substance: 5.63 mg CO_2; 1.79 mg H_2O. 3.70 mg substance: 6.15 mg CO_2; 1.90 mg H_2O. Found %: C 45.25, 45.33; H 5.87, 5.70. $C_{10}H_{14}O_8$. Calculated %: C 45.80; H 5.35.

Preparation and identification of hexanetetracarboxylic acid from the copolymer of butadiene and acrylonitrile. The tetramethyl ester of hexanetetracarboxylic acid, separated from the oxidized (with hydrogen peroxide) products of ozonolysis of the copolymer of butadiene and acrylonitrile [1], is saponified by digestion, with stirring, with hydrochloric acid diluted with an equal volume of water. Digestion is continued for 48-50 hours, after which period a small amount of insoluble resin still remains. The solution is decolorized by heating with animal charcoal and is evaporated on a bath. The residue begins to crystallize after standing for several days in a desiccator over sodium hydroxide. The crystal slurry, mixed with oil, is purified by several recrystallizations from acetone-benzene. M.p. 159-162°.

4.49 mg substance: 7.52 mg CO_2; 2.18 mg H_2O. Found %: C 45.63; H 5.39. $C_{10}H_{14}O_8$. Calculated %: C 45.80; H 5.35.

The melting point of the prepared acid corresponds to that of 1,2,4,6-hexanetetracarboxylic acid. A mixed sample of the acid from the copolymer and the synthetic product melts at 158-160°.

On the basis of these data we can definitely say that the structure of 1,2,4,6-hexanetetracarboxylic acid can be assigned to the acid derived from the copolymer.

SUMMARY

1. It is established that in the successive addition of two molecules of acrylonitrile in the copolymer molecule the α-carbon atom of one molecule adds on to the β-carbon atom of the other molecule.

2. 1,2,4,6-Hexanetetracarboxylic acid has been isolated from the butadiene-acrylonitrile copolymer and its structure elucidated.

3. 1,2,4,6-, 1,3,4,6- and 1,2,5,6-hexanetetracarboxylic acids have been synthesized.

4. A new method was developed for the preparation of the ethyl ester of β-bromopropionic acid via the hydrobromide of its imino ester.

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TERTIARY ALCOHOLS CONTAINING THE CYCLOBUTYL RADICAL

IV. REACTION OF ISOPROPYLPHENYLCYCLOBUTYL CARBINOL WITH HYDROCHLORIC AND SULFURIC ACIDS

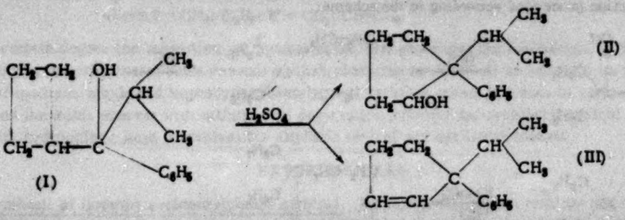
T. A. Favorskaya and I. P. Yakovlev

In previous communications [1,2,3] it was shown that when methylphenylcyclobutyl carbinol is reacted with sulfuric and hydrochloric acids it only undergoes dehydration with formation of two isomeric hydrocarbons – methylphenylmethylenecyclobutane and unsymm. phenylcyclobutylethylene. On the other hand, diisopropylcyclobutyl carbinol and ethylphenylcyclobutyl carbinol in the same conditions undergo not only dehydration but also isomerization to cyclopentane derivatives.

In this paper we consider the interaction of isopropylphenylcyclobutyl carbinol with dilute sulfuric and hydrochloric acids and also with concentrated hydrochloric acid.

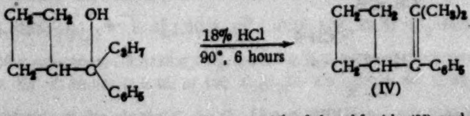
Isopropylphenylcyclobutyl carbinol (I) was synthesized from cyclobutylphenyl ketone and isopropyl magnesium bromide in 89% of the theoretical yield. A portion of the alcohol was oxidized with chromic acid mixture for investigation of its structure. Oxidation yielded isopropylphenyl ketone and a small quantity of a dicarboxylic acid with m.p. 86°. Judging by the analysis of its silver salt, this acid was *α,α*-isopropylphenylglutaric acid.

When heated with 25% sulfuric acid, isopropylphenylcyclobutyl carbinol isomerizes to 1,1-isopropylphenylcyclopentanol-2 (II), which was isolated in very small yield (1.6%) and had m.p. 57°, while the main bulk of the alcohol was dehydrated to 1,1-isopropylphenylcyclopentene-2 (III):

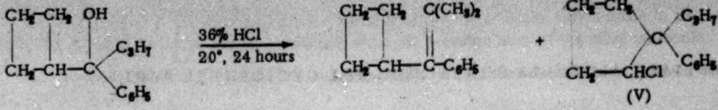


Among the products of ozonization of the unsaturated hydrocarbon (III) was found an acid with m.p. 126°; on the basis of analysis of its silver salt the formula of *α,α*-isopropylphenylglutaric acid can be ascribed to it. Obviously the acid was here obtained in a purer form than by the oxidation of the alcohol.

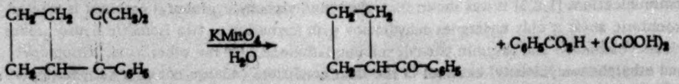
Heating with 18% hydrochloric acid for 6 hours at 30° leads to formation of 86.5% of the unsaturated hydrocarbon 1,1-dimethyl-2,2-phenylcyclobutylethylene (IV). 13.5% of the original alcohol was recovered unchanged.



With 36% hydrochloric acid, (I) gave 21% of the chloride (V) and 32% of the hydrocarbon (IV), while 47% of the alcohol was recovered unchanged. The reaction was performed at 0° for 24 hours. When the experiment was repeated at 20°, it was found that about 50% hydrocarbon and about 50% chloride (V) were formed:

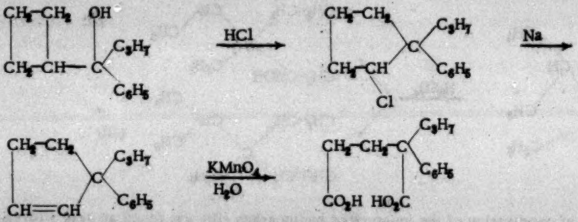


Oxidation of the unsaturated hydrocarbon (IV) with $KMnO_4$ solution proceeded very slowly and yielded cyclobutylphenyl ketone as the main product together with oxalic and benzoic acids. Acetone could not be detected. The slow oxidation of the hydrocarbon was probably due to the steric effect of the groups surrounding the double bond. The benzoic acid was formed by oxidation of cyclobutylphenyl ketone, and oxalic acid by oxidation of the succinyl residue.

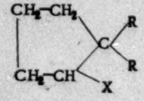


Chloride (V) had ω_{FCD} 23.6, i.e. lower than is required by a chloride containing the cyclobutyl radical (27.3). On the basis merely of the relative dispersion it can be concluded that the structure of the chloride was isomeric to that of the original alcohol. Heating of the chloride for 7-8 hours with 10% potassium carbonate and KOH solutions at the boiling temperature did not lead to reaction. It did not react in boiling absolute ether and with Mg. Heating of the chloride at 100° with sodium ethylate also gave a negative result, the chloride being recovered unchanged. Only by distillation over metallic sodium was it possible to split off HCl and to obtain an unsaturated hydrocarbon with ω_{FCD} 29.0. This behavior of the chloride indicated that it was secondary or primary but not tertiary. Oxidation of the unsaturated hydrocarbon with $KMnO_4$ solution gave a dicarboxylic acid, α,α-isopropylphenylglutaric acid, with m.p. 120-123° instead of 126° for the product of ozonization (III).

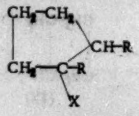
Consequently the formation of α,α-isopropylphenylglutaric acid provides confirmation that the initial hydrocarbon was 1,1-isopropylphenylcyclopentene-2, while the chloride was 1,1-isopropylphenyl-2-chlorocyclopentane. The reaction proceeded according to the scheme:



On comparing N. M. Kizhner's data [4] for isomerization with strong HBr and HI of dimethyl- and diethylcyclobutyl carbinols with our data for isomerization with hydrochloric and sulfuric acids of diisopropylcyclobutyl carbinol, we can conclude that concentrated HBr and HI act on dimethyl- and diethylcyclobutyl carbinols to bring about isomerization in the direction of expansion of the ring and formation of two isomeric halides with and without migration of the R-groups (VI) and (VII):



(VI)

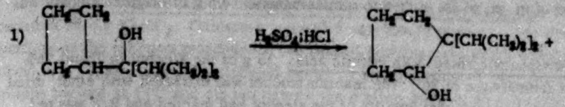


(VII)

Concentrated HCl acts on diisopropylcyclobutyl carbinol to cause isomerization with ring expansion and formation of a product of the type of (VII).

If we assign an identical isomerizing action to the halo acids, then increase in volume of R should favor the process of isomerization in the direction of derivatives of type (VI).

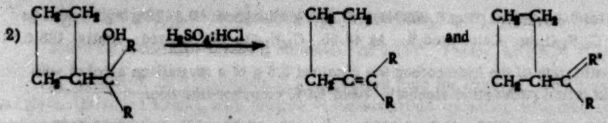
Dilute HCl and H_2SO_4 react with diisopropylcyclobutyl carbinol to form an unsaturated hydrocarbon with retention of the cyclobutane ring and to form a very small amount of an isomeric alcohol of the cyclopentane series.



Replacement of the aliphatic radical by an aromatic radical slightly changes the course of the transformation of tertiary alcohols containing the cyclobutyl radical.

Dilute hydrochloric and sulfuric acids thus act upon methylcyclobutylphenyl carbinol to cause only dehydration with formation of unsaturated hydrocarbons. No isomerization is observed.

With increasing weight of the aliphatic radical the direction of the reaction changes. Thus, ethylphenylcyclobutyl carbinol shows a greater tendency than methylphenylcyclobutyl carbinol to give unsaturated hydrocarbons without isomerization. Isopropylphenylcyclobutyl carbinol readily gives unsaturated products and chloride. In this respect there is clear evidence of the direct influence of radicals on the direction of the reaction. Whereas in the case of methyl- and ethylcyclobutyl carbinols only dehydration(and chloride formation) took place in presence of HCl and H_2SO_4 with retention of the 4-membered ring, in the case of isopropylcyclobutylphenyl carbinol only isomerization with or without dehydration of the isomerized product takes place; when using dilute hydrochloric acid dehydration takes place without isomerization.



where R = CH_3; C_6H_5; R' = CH_2; $CH-CH_3$.

To a certain degree the suggestion put forward in the first paper that the mechanism of the isomerizing and dehydrating action of mineral acids depends on their character is valid. As an example we may cite the dehydration of methyl-, ethyl- and isopropylcyclobutylphenyl carbinols which proceeds in various directions depending upon the acid; whereas with sulfuric acid dehydration involves the cyclobutyl radical and ring expansion, with hydrochloric acid it involves the aliphatic radical without isomerization.

EXPERIMENTAL

1. Synthesis of isopropylcyclobutylphenyl carbinol. To 12.5 g magnesium turnings moistened with 20 ml absolute ether was added dropwise 63 g isopropyl bromide dissolved in 200 ml ether, and then a solution of 80 g cyclobutylphenyl ketone in 100 ml absolute ether. The reaction was carried out without heating for 10 hours. The formed organomagnesium complex was decomposed with pieces of ice, the ether layer decanted off, and the residue acidified with dilute (1:5) hydrochloric acid and extracted with ether. The ether extract was washed with sodium carbonate solution, then combined with the ethereal solution and dried over Na_2SO_4. The ether was driven off and the residue distilled to give 92 g of an alcohol with b.p. 131-136° at 11 mm. A second fractionation yielded 91 g of alcohol with b.p. 131-133° at 11 mm; yield 89% of the theoretical. The alcohol was a weakly mobile, colorless liquid with a tarry odor and the following constants:

n_D^{20} 1.5325; ω_{FCD} 27.5; d_4^0 1.0248; d_4^{20} 1.0129; MR_D 62.5; calculated 62.0.

0.2029 g substance: 0.6120 g CO_2; 0.1715 g H_2O. 0.0348 g substance. 16.65 g benzene: Δt 0.053°.
Found %: C 82.31; H 9.46; M 198. $C_{14}H_{20}O$. Calculated %: C 82.35; H 9.80; M 204.

2. Oxidation of the alcohol $C_{14}H_{20}O$. 10 g of the alcohol was oxidized with 50 g potassium bichromate, 60 g sulfuric acid (s.g. 1.84) and 200 ml water. The alcohol was added dropwise to the chromic acid mixture heated to 55°. The temperature was then raised to 68°. Oxidation required 4 hours, after which the oxidation products were extracted with ether. From the ether extract was obtained 1.1 g of a dicarboxylic acid with m.p. 86° (from water) in the form of fine white crystals (α,α-isopropylphenylglutaric acid).

0.1131 g substance: 8.6 ml 0.1 N NaOH (titer 0.003941). 0.3204 g substance: 0.1488 g Ag. Found: equiv. 133.5; % Ag 46.47. $C_{14}H_{18}O_4$. Calculated: equiv. 125. $C_{14}H_{16}O_4Ag_2$. Calculated %: Ag 46.55.

From the neutral oxidation products was isolated 3.1 g isopropylphenyl ketone. The melting point of its semicarbazone was 182°. No depression of m. pt. of the authentic semicarbazone. 4.5 g of original alcohol was recovered unchanged.

3. Reaction of isopropylcyclobutylphenylcarbinol with sulfuric acid. 15 g of the alcohol in 15 ml 25% sulfuric acid was heated for 6 hours at a temperature of 90°. The reaction product was extracted with ether, dried over $MgSO_4$ and fractionated. It was found, however, that only 1/3 of the alcohol had reacted and 2/3 was recovered unchanged. The period of contact was then doubled. The amount of unconverted alcohol was then 1/3.

After repeated fractionations and two distillations over metallic sodium, a hydrocarbon was isolated with b. pt. 235-238° at 758 mm and 103-107° at 7 mm.

n_D^{20} 1.5340; ω_{FCD} 31.5; d_4^0 0.9547; d_4^{20} 0.9357; MR_D 61.79; calculated 60.65.

0.1516 g substance: 0.5033 g CO_2; 0.1260 g H_2O. 0.0639 g substance; 16.9 g benzene: Δt 0.106°. Found %: C 90.58; H 9.30; M 182. $C_{14}H_{18}$. Calculated %: C 90.32; H 9.67; M 186.0

4.6 g of the hydrocarbon was ozonized in chloroform. After removal of the solvent, the ozonide was decomposed with water with addition of 20 ml of 10% hydrogen peroxide during digestion under a reflux condenser for 10 hours, after which the solution was made alkaline to phenolphthalein with KOH. No neutral products were obtained in the ozonolysis. From the acidic products was isolated 1.2 g of an acid with m. pt. 126°. The analytical data identify it as α,α-isopropylphenylglutaric acid.

0.1210 g substance: 9.5 ml 0.1 N NaOH (titer 0.003941). 0.3321 g substance: 0.1479 g Ag. Found %: Ag 46.18: equiv. 129.3. $C_{14}H_{16}O_4Ag$. Calculated %: Ag 46.55. $C_{14}H_{18}O_4$. Calculated: equiv. 125.0.

From the residues after distillation of the hydrocarbon was obtained 0.5 g of a crystalline alcohol with m.p. 57° in the form of long, stout prisms (from ethyl alcohol). Yield 1.6%, camphor-like odor.

0.0805 g substance: 0.2412 g CO_2; 0.0707 g H_2O. 0.0769 g substance; 16.80 g benzene: Δt 0.116°. 0.1088 g substance: 14.2 ml CH_4 (14.2°, 758.2 mm). Found %: C 81.97; H 9.82, M 198.5; active H 0.55. $C_{14}H_{20}O$. Calculated %: C 82.35; H 9.80; M 204.0; active H 0.49.

By analogy with the results obtained in the investigation of the reaction of sulfuric acid with other alcohols of the cyclobutane series, this alcohol is probably 1,1-isopropylphenylcyclopentanol-2.

4. Reaction of isopropylcyclobutylphenyl carbinol with 18% hydrochloric acid. 15 g of the alcohol and 20 ml 18% hydrochloric acid were heated for 6 hours at 90°. The reaction product was diluted with 20 ml water, extracted with ether, dried over $MgSO_4$ and distilled. The main product was an unsaturated hydrocarbon (10.1 g) with b.p. 111-115°, which was combined with the hydrocarbon obtained from the alcohol by reaction with 36% HCl; in addition 2 g of a fraction with b.p. 123.5-126°, consisting of the original alcohol contaminated with hydrocarbon.

5. Reaction of isopropylcyclobutylphenyl carbinol with 36% HCl. 15 g of the alcohol and 65 ml of 36% HCl, cooled to 0°, were brought together and left at this temperature for 24 hours. The mixture was then diluted with 200 ml iced water, and the reaction product was extracted with ether, washed with water, dried over $MgSO_4$ and distilled to give three fractions: I) 107-121° (4.2 g); II) 121-130° (7.0 g); III) 135-143° (3.2 g).

The experiment was repeated at 20°. In this case the intermediate fraction was extremely small and the amounts of fractions I and III were 6.6 g and 6.1 g.

Fraction I was an unsaturated, colorless, readily mobile hydrocarbon with a camphorlike odor; after three distillations over sodium the b.p. was 105-108° at 8 mm.

n_D^{21} 1.5355; ω_{FCD} 34.5; d_4^0 0.9643; d_4^{21} 0.9482; MR_D 61.12; calculated 60.65.

0.1245 g substance: 0.4118 g CO_2; 0.1117 g H_2O. 0.0638 g substance; 17.05 g benzene: Δt 0.104°. Found %: C 90.26; H 10.04; M 180.1. $C_{14}H_{18}$. Calculated %: C 90.32; H 9.68; M 186.0.

Fraction III: chloride, a weakly mobile liquid with a yellow tint; does not decolorize permanganate solution; b.p. 140-145° at 8 mm.

n_D^{21} 1.5422; ω_{FCD} 23.6; d_4^{21} 1.0655; MR_D 65.76; calculated 65.83.

0.2860 g substance: 0.1801 g AgCl. 0.0735 g substance; 16.90 g benzene: Δt 0.105°. Found %: Cl 15.58; M 208.1. $C_{14}H_{19}Cl$. Calculated %: Cl 15.95; M 222.5.

6. Oxidation of the hydrocarbon obtained with hydrochloric acid. Oxidation of 9.5 g hydrocarbon required 26.4 g $KMnO_4$. Oxidation proceeded very slowly (4 days). The $KMnO_4$ was introduced in small portions as the reaction proceeded. The neutral products were steam-distilled, extracted with ether and dried over $MgSO_4$. Cyclobutylphenyl ketone (5.4 g) was isolated from them. The semicarbazone of the ketone melted at 177° and did not depress the melting point of an authentic specimen. Oxalic acid with m.p. 184.5° was isolated from the acidic portion. It did not depress the melting point of an authentic specimen. In addition benzoic acid (1.3 g) was found, m.p. 120.5°, no depression in mixed melting test.

7. Hydrolysis of the chloride $C_{14}H_{19}Cl$. No reaction occurred when 6 g chloride was refluxed with 100 ml of 10% potassium carbonate solution on a heater, the chloride being recovered unchanged. Similarly no reaction took place after 6 g chloride had been digested with 56 ml 10% KOH solution for 8 hours. No reaction occurred with magnesium turnings in boiling absolute ether.

8. Cleavage of HCl from the chloride $C_{14}H_{19}Cl$. 15 g dry sodium ethylate and 10.5 g chloride were heated for 5 hours under a reflux condenser at 100°. After extraction of the reaction product it was found that the chloride was recovered unchanged. It was then distilled twice over metallic sodium. From 12 g chloride was obtained 6.5 g unsaturated hydrocarbon.

The hydrocarbon was a colorless, mobile liquid with a camphor-like odor. B.p. 240-244° at 762 mm, 111-112° at 10 mm.

n_D^{20} 1.5284; ω_{FCD} 29.0; d_4^0 0.9520; d_4^{20} 0.9385; MR_D 61.07; calculated 60.65.

0.0977 g substance: 16.80 g benzene: Δt 0.157°. Found: M 184.8. $C_{14}H_{18}$. Calculated: M 186.0.

9. Oxidation of hydrocarbon $C_{14}H_{18}$ obtained from the chloride. To 6 g hydrocarbon in 100 ml water was gradually added $KMnO_4$ with progressive consumption; oxidation consumed 14.3 g $KMnO_4$. The neutral products were distilled off in steam. The amount was 1.2 g, but a pure substance could not be isolated by distillation, nor could a semicarbazone be isolated.

From the acidic portion was isolated α,α-isopropylphenylglutaric acid (2.7 g) in the form of a pasty mass, but it could not be crystallized there and then. The neutralization equivalent of the mass was 155.0 as compared with 125.0 required for a dicarboxylic acid.

0.3913 g substance: 0.1808 g Ag. Found %: Ag 46.25. $C_{14}H_{16}O_4Ag_2$. Calculated %: Ag 46.55.

After drying for 4 months on a porcelain tile and repeated crystallization from water, a minute amount of the crystals of this acid was isolated with m.p. 120-123°. Consequently, on the basis of the analysis of the silver salts and to some extent on the basis of the melting point, we can assign to this acid, like the acid obtained from the products of ozonization of 1,1-isopropylphenylcyclopentene-2, the structure of α,α-isopropylphenylglutaric acid. The structure of the products from which it was prepared by oxidation has thus been also clarified.

SUMMARY

1. Isopropylphenylcyclobutyl carbinol has been prepared.

2. It is shown that heating of isopropylphenylcyclobutyl carbinol with 25% sulfuric acid causes isomerization to a secondary alcohol of the cyclopentane series – 1,1-isopropylphenylcyclopentanol-2, the greater part of which under these conditions dehydrates to 1,1-isopropylphenylcyclopentene-2.

3. Heating of isopropylphenylcyclobutyl carbinol with 18% hydrochloric acid results in dehydration to 1,1-dimethyl-2,2-phenylcyclobutylethylene.

4. Heating of isopropylphenylcyclobutyl carbinol with 37% hydrochloric acid results in formation of equal parts of 1,1-dimethyl-2,2-phenylcyclobutylethylene and a chloride, a derivative of cyclopentane.

5. Distillation of the chloride over metallic sodium results in cleavage of hydrogen chloride with formation of the hydrocarbon 1,1-isopropylphenylcyclopentene-2.

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* See Consultants Bureau translation, p. 133.

** See Consultants Bureau translation, p. 143.

*** See Consultants Bureau translation, p. 267.

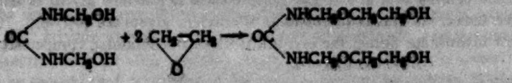
THE REACTION OF DIMETHYLOLUREA WITH ETHYLENE OXIDE

K. D. Petrov and O. K. Gosteva

The reaction of ethylene oxide with urea (as well as with other amides) was described in 1930 by Dreyfus [1] in a patent on the preparation of monoalkanolamines. In accordance with the specification the urea was added to the ethylene oxide in aqueous solutions. The prepared products were not investigated and were subjected to hydrolysis in presence of alkali with the aim of obtaining monoethanolamine.

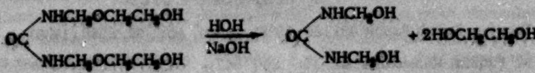
Later, Paquin [2] applied this reaction to the preparation of diethanolurea by passing gaseous ethylene oxide into a saturated aqueous solution of urea heated to 90-95°. The investigator noted that in these conditions the diethanolurea undergoes further transformations to give resins which have technical importance.

Up to the present the reaction of the most important urea derivative – dimethylolurea – with ethylene oxide has not been investigated. Dimethylolurea is known to contain, apart from the labile hydrogen atoms linked to nitrogen, extremely labile methylol groups. Consequently it resinifies readily. Resinification proceeds under the action of heat and various chemical agents, particularly acids. In our opinion ethylene oxide need not cause undesirable transformations of dimethylolurea. Thus, when heated for a long period with ethylene oxide at 100° in a sealed tube, dimethylolurea does not exhibit signs of change. In the presence, however, of dimethylaniline (which itself does not provoke visible changes in dimethylolurea), dimethylolurea entered into reaction with ethylene oxide to form a viscous, colorless oil. We took dimethylolurea and ethylene oxide in ratios of 1:2 to 1:3, and concordant results were obtained in all cases. Analysis of the oil for content of hydroxyl groups, and nitrogen and other investigations showed that the product is a dihydric alcohol [3]. The structure of the latter requires elucidation. It is known that urea in aqueous solution reacts with ethylene oxide to form diethanolurea; the question therefore arose whether in our case also the dimethylolurea added on to ethylene oxide at the amide group. To test this point, we heated urea with ethylene oxide in presence of dimethylaniline in a sealed tube in the same conditions as for dimethylolurea; no reaction between urea and ethylene oxide was here observed. We may therefore conclude that addition of dimethylolurea to ethylene oxide proceeds not at the amide group but at the hydroxyl group according to the scheme:



$$OC\begin{cases}NHCH_2OH\\NHCH_2OH\end{cases} + 2\,\underset{O}{CH_2-CH_2} \longrightarrow OC\begin{cases}NHCH_2OCH_2CH_2OH\\NHCH_2OCH_2CH_2OH\end{cases} \quad (1)$$

Evidence for this reaction course is obtained by hydrolysis of the product in presence of sodium hydroxide when ethylene glycol is formed. The latter could only result from cleavage of the bis-β-hydroxyethyl ether of dimethylolurea (I). The hydrolysis of (I) is a rather complex process, but the following reaction (leading to ethylene glycol) could take place in addition to other reactions:



$$OC\begin{cases}NHCH_2OCH_2CH_2OH\\NHCH_2OCH_2CH_2OH\end{cases} \xrightarrow[NaOH]{HOH} OC\begin{cases}NHCH_2OH\\NHCH_2OH\end{cases} + 2HOCH_2CH_2OH.$$

The foregoing considerations support the structure (I) for our product and demonstrate the mode of addition of dimethylolurea to ethylene oxide.

It should be noted in conclusion that if addition of dimethylolurea to ethylene oxide had taken place at the amide group with formation of dimethyloldiethanolurea, then hydrolysis should yield ethanolamine, whereas the latter was not found.

EXPERIMENTAL

Preparation of bis-β-hydroxyethyl ether of dimethylolurea. The starting material was dimethylolurea with m.p. 129°. We give details of one of the numerous experiments.

Into a stainless steel tube were introduced 50 g (0.416 mole) dimethylolurea, 55 g (1.25 mole) ethylene oxide, a few drops (3-4 drops) dimethylaniline and 50 ml benzene. The tube was hermetically sealed and attached to the rotating shaft of a water bath whose temperature was maintained at 95-100°. The reaction proceeded for 2-1/2 hours. At the conclusion of the reaction the product was extracted from the tube, cooled, separated from the benzene layer and further heated in vacuum on the water bath for removal of traces of benzene and other volatile impurities.

Distillation was effected at first in a low vacuum and later at 3-4 mm, the bath temperature being brought to 130°. The yield of bis-β-hydroxyethyl ether of dimethylolurea was quantitative.

To the naked eye the substance is a viscous, transparent, yellow oil: n_D^{22} 1.5044. When prepared in a glass ampoule, however, the product is colorless.

d_{20}^{21} 1.2830; n_D^{21} 1.5010; MR_D 47.53; calculated 45.58.

0.3682 g substance: 0.5586 g CO_2; 0.2706 g H_2O. 0.4839 g substance: 0.7345 g CO_2; 0.3602 g H_2O. Kjeldahl nitrogen determination: 1.0720 g substance: 9.83 ml 1 N H_2SO_4. Determination of hydroxyl groups by phthalation: 0.5031 g substance: 9.62 ml 0.5 N KOH. 0.2230 g substance: 4.19 ml 0.5 N KOH. 0.4938 g substance: 37.03 g water; Δt 0.120°. Found %: C 41.39, 41.42; H 8.22, 8.36; N 12.84; OH 16.25, 15.98; M 206. $C_7H_{16}O_5N_2$. Calculated %: C 40.34; H 7.69; N 13.46; OH 16.35; M 208.

Hydrolysis of bis-β-hydroxyethyl ether of dimethylolurea. Into a round-bottomed flask, fitted with stirrer and reflux condenser, were introduced 104 g (0.5 mole) bis-β-hydroxyethyl ether of dimethylolurea and 100 ml 1 N sodium hydroxide. The contents of the flask were heated on an oil bath to the boiling point of the reaction mixture. Hydrolysis was carried out for 20 hours.

At the conclusion of hydrolysis, the reaction mass was cooled and transferred to a Claisen flask for removal of water by distillation on the water bath while connected to a water jet pump. The distillate had an ammoniacal odor. After the water had been distilled off, the reaction product was extracted with 300 ml butanol. The butanol was subsequently distilled off in a low vacuum; the residue was filtered and subjected to fractionation. The main fraction came over at 104-106° (12-15 mm). The product weighed 12 g and was a transparent liquid. It contained 47.20% OH and traces of nitrogen: d_{20}^{20} 1.1126; n_D^{20} 1.4401.

Fractionation of the liquid at normal pressure gave the following results: I, up to 194°, 0.5 g, n_D^{20} 1.4300; II, 194-198°, 6 g, n_D^{20} 1.4324 d_{20}^{20} 1.1126; III, 198-200°, 2 g, n_D^{20} 1.4370; IV, 200-205°, 1 g; still residue 2.5 g.

The substance coming over at 194-198° corresponded to ethylene glycol in specific gravity, boiling point and refractive index; the literature constants of ethylene glycol are [4]: b.p. 197.5°, d_{20}^{20} 1.1151; n_D^{20} 1.4335. We did not investigate further the crystalline nitrogen-containing compounds isolated from the alkaline hydrolyzate.

SUMMARY

The reaction between dimethylolurea and ethylene oxide is described and the mode of addition of dimethylolurea to ethylene oxide is clarified.

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NEW TYPES OF TERPENE TRANSFORMATIONS

XI. THE ACTION OF CHLORINE ON α-FENCHENE

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Derivatives of fenchenes with the composition $C_{10}H_{15}X$ are almost unknown. The action of chlorine on fenchenes has not been investigated. Since monochlorterpenes of the allylic type obtained by us for the first time can be transformed into diverse terpene derivatives of the general composition $C_{10}H_{15}X$ (see previous communications), it is a matter of some interest to investigate the action of chlorine on fenchenes and the further transformations of the chlorfenchenes.

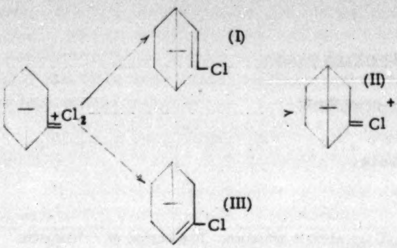
As we know, fenchenes are not found in nature and are prepared by removing water from fenchyl alcohol; this process always gives a mixture of fenchenes in which one isomer or the other predominates according to the method of dehydration. Consequently the preparation of fenchenes necessitates the use of one fenchyl alcohol or another.

Lyubomilov, Rutovsky and Sheremeteva [1] report that the liquid chloride which is a by-product of the action of hydrogen chloride on pinene can be converted under the action of potassium phenolate into a hydrocarbon $C_{10}H_{16}$. The latter can give, by the Bertram-Walbaum method, the acetate of isofenchyl alcohol. Unfortunately the authors did not state the yield of this ester. We repeated this work and found that the top terpene fractions (up to 160°), obtained from the chloride which did not solidify at −14° and which corresponded in boiling point to a mixture of fenchenes, solidified partially at only −23° and completely at −70°; this indicated the high content of camphene therein and in turn the high content of bornyl chloride in the liquid chlorides. We then froze out a solid fraction at −54° (it, too, proved to be bornyl chloride) and worked up the liquid portion by the method of Rutovsky and co-workers. In this case also, the fraction up to 160° partly solidified at −23°. It became clear from the foregoing remarks that these liquid chlorides do not constitute the raw material for an acceptable synthesis of the fenchene isomers.

It is known [2] that fennel oil has a fenchone content of 0 to 15-18% depending mainly on the place of cultivation of the fennel. The main constituent of this oil is anethole. At some perfumery factories fennel oil is oxidized with chromic acid mixture to convert the anethole into anisaldehyde, and the aldehydes are extracted from the product of reaction with bisulfite solution. Since fenchone is extremely stable to the action of oxidizing agents, it might be thought that the portion of the reaction product not soluble in bisulfite would be enriched in fenchone; this was found to be the case by experiment. By this very simple method (see experimental) we obtained pure fenchone in a yield of about 30% from this waste product of the anisaldehyde industry. In this way we solved the problem of finding a starting material for the synthesis of fenchenes.

The first stage in the synthesis is the reduction of d-fenchone to 1-fenchyl alcohol (mixture of the α- and β-isomers). After trying out a number of methods we decided that the simplest, most convenient and safest method was reduction with isopropyl alcohol in presence of aluminum isopropylate [3]. In this way we obtained 1-fenchyl alcohol in nearly quantitative yield. Dehydration of fenchyl alcohol gives a mixture of fenchenes. The Qvist method [4] (heating of the alcohol with aluminum phosphate) gives a mixture containing over 50% α-fenchenes. We also tried this method and fractionated the resultant mixture of fenchenes in a column with an efficiency of about 40 theoretical plates. The fenchene isomers were isolated in the pure form. The α-fenchene yield from the mixture was 59%; its specific rotation (−38.2°) was higher than that of any other sample of α-fenchene described in the literature; we therefore considered that our α-fenchene was of adequate purity.

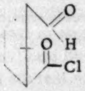
Reaction of α-fenchene with chlorine was effected in the previously described conditions [5] with cooling of the reaction mixture to −2° and −6°. In line with the previously developed considerations [6] the action of chlorine on α-fenchene may be represented by the following scheme (the saturated dichloride is not shown):



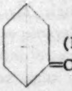
The yield of monochlorides determined from the amount of hydrogen chloride ("anomalous" reaction) fluctuated round 63%, which is not remarkable: we had previously shown [7] that the highest yield from this reaction must occur when the positive end of the double bond is attached to one or two methyl groups with their more highly protonized hydrogens. In the present case the double bond has attached to it a methylene and a methylene group. Consequently the most probable course of reaction (I) will not be realized with a sufficiently high yield (due to the "methylene" prohibition), as we have already observed in the case of β-pinene [5]. Formation of chloride (III) is very much less probable (Bredt prohibition). Formation of chloride (II) is analogous to the formation of 1-chlor-2,2'-diphenylethylene by the action of chlorine on 2,2'-diphenylethylene: in the latter case the removal of a hydrogen atom from the phenyl group with the labile double bond is impossible, and the chlorine anion captures the hydrogen from the methylene group which is protonized by the action of the chlorine cation undergoing attachment. In our case the migration of the double bond with formation of chloride (I) is not excluded but is hindered ("methylene" prohibition), and hence chloride (II) must be formed in small yields. Previously we discussed [6] the predominance of this course of chlorination in the case of the extremely "prohibited" molecule of camphene.

The α-fenchyl monochloride isolated from the chlorination products has a sharp boiling point, which points to the absence of chlorides with different positions (primary, secondary and tertiary) of the atoms of chlorine. On the other hand it exhibits appreciable exaltation of the molecular refraction (+0.3) which is not consistent with the presence solely of chloride (I) and points to contamination with chloride (II) with a hemicyclic double bond. The contents of total and saponifiable chlorine (20.6 and 16.2%) also point to the same conclusion: it contains three parts chloride with labile double bond [possibly (I)] and one part of an unsaponifiable chloride [possibly (II)]. Further investigations confirmed the correctness of these suppositions.

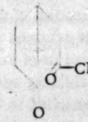
Ozonolysis of the mixture of chlorides should give from chloride (I) a chlorketone with the composition $C_{10}H_{15}O_2Cl$ (I'), from chloride (II) a fenchocamphorone with the composition $C_9H_{14}O$ (II'), and from chloride (III) a chlordiketone with the composition $C_{10}H_{15}O_2Cl$ (III').



(I')

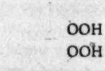


(II')



(III')

On further oxidation only (I') will give cis-apocamphoric acid



, (II') is stable to oxidation, (III') will not give the acid.

Actually, ozonolysis only gives the chlorketoaldehyde (I') which is oxidized to cis-apocamphoric acid. Fenchocamphorone could not be isolated after ozonolysis of the mixture of chlorides. Chloride (II) was detected in the mixture after conversion of chloride (I) into the acetate of fenchenol which has a higher boiling point than chloride (II) (the latter does not react with potassium acetate). Ozonolysis of the isolated chloride (II) gave fenchocamphorone which was characterized in the form of the semicarbazone.

Chloride (I) is a derivative of γ-fenchene. Substitution of its chlorine by the hydroxyl group will give the unknown γ-fenchenol if this transformation is not accompanied by an allyl rearrangement, and it will give the unknown α-fenchenol if an allyl rearrangement ensues. As was pointed out in the preceding communications, the thermodynamic probability of such a rearrangement is extremely low. Transformation of the chloride into the alcohol was effected by the usual method via the acetate by heating (I) with potassium acetate in boiling acetic acid. The ester is obtained in good yield; its molecular refraction is normal, pointing to the absence of the ester of α-fenchenol with a hemicyclic double bond. The derived γ-fenchenol yielded an acid phthalate when heated with phthalic anhydride in boiling benzene, demonstrating the primary character of the alcohol. The same alcohol was oxidized by chromic acid in acetic acid to the corresponding aldehyde. Consequently our prepared alcohol can be taken to be γ-fenchenol, corresponding to chloride (I) in structure. It is the first representative of the alcohols of the γ-fenchene series.

EXPERIMENTAL

1. Check of the possibility of preparing fenchyl alcohol from the liquid monochlorides of composition $C_{10}H_{17}Cl$, forming a by-product of the preparation of bornyl chloride from pinene. Technical monochloride (1338 g) was fractionated in a column to give 242 g terpenes. The residue was frozen at −14° and 362 g crystals (bornyl chloride) were drained off; the filtrate was fractionated in a plate column to give eight fractions. The first six fractions solidified at +20°; these were drained at the pump and the filtrate again frozen at −14° to give 554 g of crystals (41% of the batch weight) and 242 g of chlorides with composition $C_{10}H_{17}Cl$ liquid at −14° (18%). A portion of the liquid chlorides was converted into terpenes by Rutovsky's method [1]. The 150-160° fraction (all the fenchenes boil below 160°) solidified at −23°; consequently it mainly consists of camphene. The original liquid chloride was then frozen at −54° and the crystals (bornyl chloride, 60%) drained at the pump. The chlorides remaining liquid at −54° were about 70% technical monochloride; they were again converted into terpenes which boiled at 155-175°. The fraction up to 160° was again frozen at −23° but not completely. It was concluded that this method could not give fenchenes in satisfactory yield.

2. Preparation of fenchone. The sodium bisulfite-insoluble portion of the products of oxidation of fennel oil with sulfuric acid solution of bichromate (8967 g) was steam-distilled. Distillation was stopped when 5 ml oil per 100 ml water came over. The amount of distilled oil was 5397 g (60%); the residue was 3402 g (38%). The oil was fractionated in a column with 6-8 theoretical plates and at a pressure of 10-11 mm. Fractions corresponding to fenchone in boiling point were combined and again fractionated in the same conditions. 307 g of fractions was obtained with boiling point at atmospheric pressure of 185-191.5° (10.4% yield on the volatile oil); 1347 g (46%) was obtained with boiling point 191-193.5° (the boiling point was determined by distilling 10 g from a small Wurtz flask which accounts for the wide range; in vacuum, on a column, the fraction boiled sharply). Its constants were: d_4^{20} 0.9408; n_D^{20} 1.4623; $[\alpha]_D^{20}$ + 78.3°. The oxime was prepared by Wallach's method [8]; the melting point of the first precipitate was 164-166°; that of the second precipitate, after dilution of the mother liquor with a little water, was 164-165°. 10 g of fraction gave 8.9 g oxime. The main 185-191.5° fraction was purified by digestion with triple the volume of nitric acid (density 1.41) until nitrogen oxides ceased to come off. Fenchone was obtained from it (by dilution with water, steam-distillation and fractionation) in a yield of 55% of the top fraction. Its constants were: b.p. 191-192.5°; d_4^{20} 0.9429; n_D^{20} 1.4624; m.p. of oxime 165-166°.

3. Reduction of fenchone. Into a round-bottomed flask, heated to 45-50° and fitted with a reflux condenser, are introduced a weighed amount of aluminum turnings, absolute isopropyl alcohol in weight equivalent to one-eleventh of the weight of the aluminum turnings, and mercuric chloride in amount equivalent to 5% of the weight of the aluminum turnings. After solution of the aluminium, the flask is connected to a column with 7-8 theoretical plates and addition is made to the flask of fenchone in amount equivalent to ten times the weight of the turnings, dissolved in three times the volume of isopropyl alcohol. The flask is heated on the boiling water bath and the acetone formed is taken off with a reflux number of 25-30 (vapor temperature 58-65°). After 40 hours addition is made of isopropyl alcohol in amount equal to 1-1½ times the amount of fenchone and heating is continued for a further 40 hours. About 65% of the theoretical amount of acetone collects in the distillate (determined by the oxime method). The reaction product is agitated with double the volume of water, the aluminium hydroxide precipitate is dissolved in the calculated amount of aqueous hydrochloric acid, and the aqueous layer is separated from the oil layer. The isopropyl alcohol-water azeotrope is distilled off from the aqueous layer on a column; the oily layer is first fractionated at atmospheric pressure to remove isopropyl alcohol and then in vacuum with a reflux number of 10-12. After taking off the fenchone intended for fresh reduction, the tap of the receiver and the dephlegmator of the column become choked with crystals of fenchyl alcohol if the temperature of the water in the dephlegmator is not higher than 10°. The column is then replaced by a small tray still and the fenchyl alcohol distilled off. If the water temperature exceeds 10°, then the fenchyl alcohol fraction is taken off at the boiling temperature at atmospheric pressure (199-201°), and with a specific rotation of −10°, −14°. The fraction intermediate between fenchone and the alcohol is redistilled. The yield of the alcohol, allowing for the recovered fenchone, is nearly quantitative.

4. Dehydration of fenchyl alcohol. 47 g fenchyl alcohol and 13 g $AlPO_4$ are heated on a metal bath (bath temperature 210-220°) until oil-water mixture ceases to come off; the residue of oil in the catalyst is then removed by blowing with steam. 40.4 g oil was obtained. In this manner 536 g alcohol was worked up

to give 460 g oil. This was fractionated in a column equivalent to 40-45 theoretical plates at a pressure of 9 mm and a reflux number of 15-16. There was obtained a top fraction of 32 g (b.p. 139-142° at atm. pressure), a middle fraction of 227.4 g, and a residue of 153 g; the loss was 45 g. The residue was put aside for fresh dehydration and the middle fraction was refractionated in the specified conditions for isolation of fractions with constant boiling points; this involved three rectifications. The constants of the fractions are given in the table. The boiling points of the fractions at atmospheric pressure were determined by fractionation of small samples from a Wurtz flask and are therefore not sharp.

B.p. (760 mm)	Weight (g)	d_4^{20}	n_D^{20}	MR_D		ΣMR_D
				Calculated	Found	
147-148°	35.3	0.8616	1.4613	43.511 γ-fenchene	43.41	−0.1
151-153	20.7	0.8663	1.47105	43.911 β-fenchene	43.933	+0.022
155-156	102.6	0.8699	1.4734	43.911 α-fenchene	43.931	+0.02

Comparison of the constants of our specimen of α-fenchene ($[\alpha]_D$ −38.2°) with those obtained by other authors [9] shows that our specimen is superior both in specific rotation and in refraction.

5. Chlorination of α-fenchene was performed under the usual conditions (with cooling to −2° to −6°): α-Fenchene 50 g, $KMnO_4$ 12.5 g, HCl 70 ml, $NaHCO_3$ 30 g, duration of chlorination 2 hours 45 minutes.

The amount of Cl' found in the salts was 4.1 g, that in the wash bottles was 0.4 g; the organic portion contained 9.7 g chlorine; the percentage of anomalous reaction was 63.4. The organic portion amounted to 55.4 g of which 51.9 g was fractionated in a small column. After distilling off the α-fenchene (21 g) a monochloride fraction (18.7 g) was collected with specific gravity 1.012; the residue of 7.5 g had specific gravity 1.112; the loss was 4.8 g.

The monochloride was fractionated in the same column at 2.3 mm to give: First fraction (following a few drops at 41-53°) at 53-55°, 5-7 g, d_4^{20} 1.000; n_D^{20} 1.4895; second fraction at 55°, 10.4 g; residue 0.7 g; loss 0.4 g.

d_4^{20} 1.018; n_D^{20} 1.4931; MR_D 48.71; calculated 48.38.

Found %: Total Cl 20.6; allyl Cl 16.2, 15.9. $C_{10}H_{15}Cl$. Calculated %: Total Cl 20.7.

9.5 g of the second fraction in 100 ml chloroform was ozonized (under ice cooling) with 55 1 4.1% ozone until the reaction to bromine was negative. The chloroform solution of the ozonide was decomposed by stirring with 200 ml iced water for 6 hours. The chloroform layer was separated, and the chloroform distilled off to leave a residue of 11.45 g; the latter was fractionated in vacuum (0.001 mm). The main fraction (3.6 g) came over at a bath temperature of 160-180°.

d_4^{20} 1.164; n_D^{20} 1.4997; MR_D 51.18. $C_{10}H_{15}ClO_2$ (chlorketoaldehyde); calculated 51.07.
Found %: C 58.2, 57.9; N 7.4, 7.3; Cl 19.9. $C_{10}H_{15}ClO_2$. Calculated %: C 59.2; H 7.4; Cl 17.5.

Oxidation of the chlorketoaldehyde. To 3.8 g of aldehyde in 100 ml acetone and 10 ml water was added a 4% permanganate solution in acetone until the color remained unchanged (195 ml) while heating to 40° on a bath. The manganese dioxide was drained at the pump and extracted three times with boiling water. The combined filtrates were concentrated to 30 ml, acidified with hydrochloric acid (to congo) and repeatedly extracted with ether. The ether was removed from the extract, the solid residue was recrystallized from hot aqueous alcohol: Needles in star-like clusters, m.p. 204-206°; g-equivalent 93.2, corresponding to cis-apocamphoric acid [10].

6. Action of potassium acetate on α-fenchyl chloride. Chloride 24.4 g, potassium acetate 38 g and acetic acid 110 ml were digested for 3 hours. The solution was diluted with water to 1 liter and extracted with ether; in the aqueous layer was found 7.2 g KCl, yield 68 %. From the ether extract, following neutralization of the acid with caustic alkali, the ether was driven off and the residue was fractionated in vacuum to give two main fractions: I) 57-59° (1.5 mm), 5.7 g; d_4^{20} 1.000; n_D^{20} 1.4793 (monochloride, see below); II) 74-75° (3 mm), 14.6 g.

d_4^{20} 0.996; n_D^{20} 1.4711; MR_D 54.46. $C_{10}H_{15}OCOCH_3^{F}$; calculated 54.40.

13.5 g of fenchyl acetate was saponified by digestion for 6 hours with 5 g potassium hydroxide in 40 ml ethanol. The ethanol was distilled off on the water bath, the residue diluted with water and extracted with ether, and the ether extract fractionated to give one main fraction; 74° at 3 mm, 6.9 g.

d_4^{20} 0.9876, n_D^{20} 1.4935; MR_D 44.8. $C_{10}H_{15}OH\ulcorner$; calculated 45.0.

It was qualitatively established that fenchenol in boiling benzene reacts with phthalic anhydride to form the acid phthalate, melting at about 140°. A mixture of equal amounts (1 g each) of fenchenol and the anhydride was then heated at 130° for 10 minutes, the melt extracted with sodium carbonate solution, the solution acidified, and the precipitate twice recrystallized from gasoline; fluffy needles, m.p. 144°; gram-equivalent found 299, calculated for $C_{18}H_{19}CO_2COOH$ 300.

5 g fenchenol was oxidized, under cooling, with 2.2 g chromic acid in 25 ml acetic acid. The solution was diluted with water and blown with steam; the oil from the distillate was extracted with ether, the ether driven off, and the residue fractionated at 3 mm. A fraction was collected whose constants corresponded to terpenol: b.p. 61-63°; d_4^{20} 0.952; n_D^{20} 1.4808. It gave all the qualitative reactions for an aldehyde. The semicarbazone, prepared in the usual manner, had m.p. 102-104° (from methanol).

7. Determination of the structure of the α-fenchyl monochloride not reacting with potassium acetate. 1.8 g monochloride in 50 ml chloroform was ozonized with 12 liters of 4 % ozone until the reaction for bromine was negative. The ozonide solution was decomposed by stirring for 6 hours with iced water; the chloroform layer was separated, the chloroform distilled off, and the residue distilled with steam.

The distillate was extracted with ether, the ether was removed from the extract; the residue partly solidified. To 1 g of residue was added a solution of 2 g semicarbazide acetate in 50 ml alcohol. After 24 hours the solution was concentrated to 10 ml; the precipitated crystals were recrystallized from hot alcohol until the m.p. was constant at 210-212°, which corresponds to the semicarbazide of fenchocamphorone [11].

Found%: N 22.1 (Dumas). $C_{19}H_{17}ON_3$. Calculated %: N 21.5.

SUMMARY

1. It is shown that Rutovsky's method is unsuitable for the synthesis of fenchyl alcohol.

2. A simple method was developed for the preparation of fenchone from available raw material and for the reduction of fenchone to fenchyl alcohol.

3. Fenchyl alcohol was converted into extremely pure α-fenchene in good yield.

4. Chlorine acts on α-fenchene to give γ-fenchyl chloride and ω-chlor-α-fenchene. The first of these was converted into the corresponding γ-fenchenol.

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* See Consultants Bureau translation, p. 931.

** See Consultants Bureau translation, p. 593.

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NEW TYPES OF TERPENE TRANSFORMATIONS

XII. SYNTHESIS OF NITRILES OF THE HOMOTERPENE SERIES

D. Tishchenko, N. Persiantseva and V. Poliadov

Certain nitriles of the terpene series with the composition C_9H_{15}–CN are known and can be prepared by dehydration of the oximes of the corresponding aldehydes; by contrast, the homoterpene nitriles with the composition $C_{10}H_{15}$–CN are practially unavailable. Development of a general method for their synthesis is desirable if only because, by means of a series of known transformation, we can pass from them to the almost unknown homoterpene derivatives such as the aldehydes, acids, ketones amines and imines.

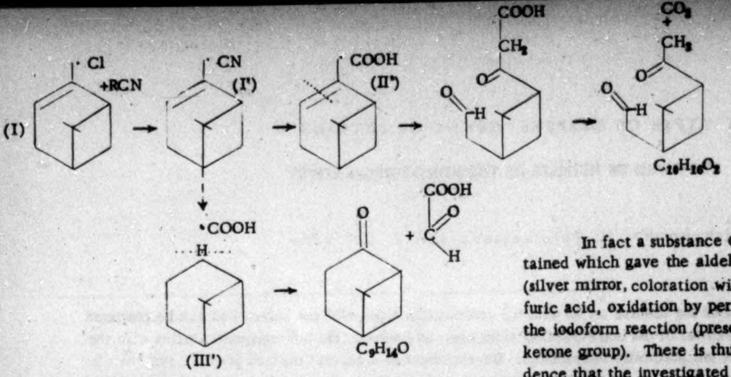
The chlorterpenes of the allyl type prepared by us contain a labile chlorine atom capable of anion exchange reactions. In communication VII [1] we put forward certain considerations enabling the establishment of the most favorable conditions for transformation of our chlorterpenes into other terpene derivatives with the help of anionic exchange. The most important of these is the presence in the reaction medium of only that anion which is necessary for formation of the desired substance. This was experimentally demonstrated by reaction of myrtenyl chloride with potassium acetate in ethanol, which gives not only myrtenyl acetate but also ethyl myrtenyl ether due to addition of the ethoxyl ion to the myrtenyl cation.

In the saturated series the synthesis of nitriles is effected with satisfactory yields by reacting halohydrins with an aqueous or alcoholic solution of alkali cyanides. On the basis of the foregoing considerations it can be predicted that this method is unacceptable for the present case. Alkali cyanides are strongly solvolyzed by ionogenic solvents and the solution will contain a high concentration of hydroxyl or alkoxyl ion which leads to formation of either alcohols or alkyl terpenic ethers. An experimental test confirmed this prediction: On reacting myrtenyl chloride with an ethanol solution of potassium cyanide, ethyl myrtenyl ether was obtained in nearly quantitative yield together with only traces of nitrile.

At high temperatures certain chlorterpenes break down with appreciable speed to dehydroterpene $C_{10}H_{14}$ and hydrogen chloride. In connection with the preparation of nitriles, therefore, we must seek cyanides which do not react, or only react with difficulty, with hydrogen chloride in order to avoid the release of hydrocyanic acid during the transformation. After several exploratory experiments we decided to make use of cuprous cyanide in a medium of boiling aromatic hydrocarbons for the synthesis of terpene nitriles. The reaction was found to proceed with extraordinary slowness in boiling benzene (check by determination of amount of inorganic chlorine), rather more quickly in boiling toluene, and with adequate speed in boiling xylene. Hardly any hydrocyanic acid was evolved, indiating that the reaction proceeds in the desired direction.

Myrtenyl chloride (I) and the chloride of carveol (6-chlordipentene, II) were consequently brought into reaction with cuprous cyanide. The nitrile of homomyrtenic acid was obtained from (I) in about 50 % of the theoretical yield, the nitrile of dipentenylformic acid was obtained from the chloride (II) in about 30% yield. Both are fairly mobile liquids with a characteristic nitrile odor, specific gravity about 0.95-0.96 and refractive index about 1.50. Both nitriles were saponified to the corresponding acids. Acid saponification is excluded in the present case, particularly for myrtenyl cyanide (I'), due to the possibility of fusion of the four-membered ring. Saponification was therefore performed with alcoholic caustic alkali. The corresponding terpenyl formic acids were obtained in good yields. We know that aqueous alkali can cause migration of the double bond in unsaturated acids [2], and it was consequently necessary to check, by one example at least, whether such a migration takes place during saponification of our nitriles.

On the basis of this method of preparation the structure (I') must be assigned to myrtenyl chloride and (II') to the acid derived from it. If double fond migration had occurred during saponification of the nitrile, the structure (III') must be assigned to the acid. Ozonolysis of acids (II') and (III') will give different products: Acid (II') will give an α-ketoaldehyde acid which in turn will give a ketoaldehyde $C_{10}H_{16}O_2$ and carbon dioxide; acid (III') will give nopinone $C_9H_{14}O$ and carbon dioxide:



In fact a substance $C_{10}H_{16}O_2$ was obtained which gave the aldehyde reactions (silver mirror, coloration with fuchsine sulfuric acid, oxidation by permanganate) and the iodoform reaction (presence of methyl ketone group). There is thus adequate evidence that the investigated acid has the structure (II') corresponding to the structure of the original chloride.

EXPERIMENTAL

(Transformations of chloride I were performed by N. Persiantseva, those of chloride II by V. Foliadov.)

Chloride (I). Small weighed amounts of the chloride were heated for various periods with excess of cuprous cyanide in boiling benzene, toluene, xylene, and the reaction yield determined from the amount of inorganic chlorine. With benzene the yield did not exceed a few per cent; with toluene it was 8% after 2 hours and 26% after 6 hours; with xylene it was 63% after 3 hours.

100 g chloride, 50 g cuprous cyanide and 500 g xylene were heated for 5 hours at the boil, after which the copper salts were filtered at the pump, the low-boiling substances (xylene, etc.) were distilled off on the boiling water bath in the vacuum of a water jet pump, and the residue fractionated in a small column at a pressure of 3 mm. One main fraction (38 g) was obtained with b.pt. 99-102°.

d_4^{20} 0.961; n_D^{20} 1.4889; MR_D 48.34. $C_{10}H_{15}CN$ F□ . Calculated 48.30.

Found %: N 8.53, $C_{11}H_{15}N$. Calculated %: N 8.69.

Saponification of the nitrile. 15 g nitrile was heated with 12 g potassium hydroxide in 100 ml 85% alcohol until no more ammonia came off (76 hours). After the alcohol had been distilled off, the neutral substances were extracted from the solution with ether and the alkaline solution was acidified with hydrochloric acid (to congo) and extracted with ether. The ether was removed from the ether extract and the residue fractionated in a small column at a pressure of $1 \cdot 10^{-3}$ mm. A main fraction was obtained (10.5 g) with b.p. 110-112°. A viscous liquid:

d_4^{20} 1.048; n_D^{20} 1.4977; MR_D 50.29. $C_{10}H_{15}COOH$ F□ . Calculated: 50.07.

Found %: C 73.0, 73.3; H 8.8, 8.8; equiv. 179.7, 178.7. $C_{10}H_{15}COOH$. Calculated %: C 73.3; H 8.9; equiv. 180.

Ozonization of the acid. 7 g acid in 100 ml chloroform was treated with 58 liters 4% ozone for removal of the reactivity to bromine. The chloroform solution of the ozonide was added dropwise to iced water with stirring, 1 g manganese dioxide was added and the stirring continued until the reaction for peroxide was negative. The manganese dioxide was drained off at the pump and the chloroform layer fractionated. The main fraction came over at 45° (0.000001 mm) and gave all the aldehyde reactions and the iodoform test.

Found %: C 70.1, 69.9; H 9.7, 9.9. $C_{10}H_{16}O_2$. Calculated %: C 71.4; H 9.5.

Chloride (II). 49 g 6-chlordipentene, 32 g cuprous cyanide and 300 ml xylene were heated for 3 hours at the boil, after which the copper salts were filtered at the pump, washed with xylene and dried. The dry salts were fused with a mixture of 32 g Na_2CO_3 and 64 g $KHCO_3$ (inflammable vapor came off in large volume during fusion) and the melt was dissolved in water, the solution filtered from the precipitate and made acid to phenolphthalein in a draft at the boil. In the solution was found 8.55 g chlorine ion; the reaction had proceeded to the extent of 85%. The xylene was distilled off from the xylene solution in a column at 20 mm to leave 36.2 g residue which was then fractionated at 1 mm. Up to 95°, 0;5 g; fraction I) 98-99°, 5.8 g; fraction II) 99-103°, 4.2 g; undistillable viscous residue 14.2 g (nitrogen content 4%).

Fraction I: d_4^{20} 0.9577; n_D^{20} 1.5001; MR_D 49.49. $C_{10}H_{15}CN\ulcorner_2$. Calculated 49.63.

Found %: N 8.48. $C_{11}H_{15}N$. Calculated %: N 8.69.

Fraction II: d_4^{20} 0.9556; n_D^{20} 1.5036; MR_D 48.89 g.

Found %: N 8.50.

Saponification of the nitrile. 3.9 g cyanodipentene and 25 ml 25% potassium hydroxide were heated to boiling until ammonia ceased to come off (17 hours). The nitrile odor was still detectable. The solution was steam-distilled and extracted with ether for removal of neutral substances. The alkaline solution was made acid to congo and extracted with ether. The ether was removed from the extract to leave a residue of 3.0 g. Gram-equivalent found 200.6; calculated for $C_{10}H_{15}COOH$ 180. The oil was subjected to molecular distillation at 0.001 mm when a large portion (1.1 g) came over at a bath temperature of 90-100°. The crystals were drained from the semisolid distillate and pressed on paper; m.p. 39-40°; gram-equiv. 181.6.

Liquid portion: Found %: C 73.1; H 9.1; equiv. 178.6. $C_{10}H_{15}COOH$. Calculated %: C 73.3; H 8.95; equiv. 180.

The liquid and solid portions may be stereoisomers of 6-dipentenylformic acid.

SUMMARY

1. Chlorides (I) and (II) are used as examples to show the possibility of transformation of the chlorterpenes prepared by us into the nitriles of the corresponding terpenyl formic acids.

2. Saponification of the nitriles gave these acids. It is shown that migration of the Δ^3double bond to the Δ^4-position [10] does not take place during synthesis of myrtenyl formic acid.

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[1] J. Gen. Chem., 22, 803 (1952).*

[2] See, e.g. Becker, Tautomerism, 132 et seq. (1937), State Sci.-Tech. Press, Moscow.

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* See Consultants Bureau translation, p. 865.

SYNTHESIS AND PROPERTIES OF ETHERS OF DISECONDARY γ-GLYCOLS

I. PREPARATION OF THE METHYL AND ETHYL ETHERS OF DIPHENYLBUTYNEDIOL

Yu. S. Zalkind*, E. D. Venus-Danilova and V. N. Mikhailova

Ethers of disecondary γ-glycols of the acetylenic, ethylenic and saturated series have scarcely been investigated.

The acetylenic derivatives only became accessible to investigation after the discovery by Zh. I. Iotsich [1] of a method of synthesis of γ-glycols via organomagnesium compounds. Apart from this method, ditertiary γ-glycols are obtained as by-products in the condensation of acetylene with ketones in presence of potassum hydroxide by A. E. Favorsky 's reaction [2].

The simplest method of synthesis of ethers of acetylenic γ-glycols is the direct action of monohydric alcohols on a glycol in presence of an acidic catalyst, as first carried out by G. A. Arbuzov [3]. The author used a small amount of iodine as catalyst on the assumption that hydriodic and hypoiodous acids are always formed by the action of water (always present in the alcohol) during the etherization of the glycols. The correctness of this assumption was later confirmed by Yu. S. Zalkind and P. S. Bataev [4].

A large number of ethers of disecondary acetylenic γ-glycols containing aliphatic and aromatic radicals were prepared by Sh. Mamedov who used concentrated sulfuric acid as catalyst. It is necessary to point out that ethers are by no means invariably formed by heating glycols with the appropriate alcohols in presence of a small quantity of acid.

For example, according to Yu. S. Zalkind, E.D. Venus-Danilova and V. I. Ryabtseva [6, 7, 8], when unsymmetrical dimethyldiphenylbutynediol is heated with ethyl alcohol in presence of various amounts of sulfuric acid the anticipated ether was not obtained, but instead a diketone, furanone and ethoxydihydropyran-2,5. When attempts were made to prepare the phenyl ethers of tetraphenylbutynediol [9], tetramethylbutynediol [10] and unsymmetrical dimethyldiphenylbutynediol [6] in presence of sulfanilic acid, products of condensation of the respective glycols were isolated as well as products of their further transformation.

In the present communication the synthesis is described of the full methyl and ethyl ethers of diphenylbutynediol and their reduction to the corresponding ethers of diphenylbutenediol and diphenylbutanediol.

$$C_6H_5CH(OR)-C\equiv C-CH(OR)-C_6H_5 \xrightarrow[Pd]{H_2} C_6H_5CH(OR)-CH=CH-CH(OR)-C_6H_5 \xrightarrow[Pt]{H_2}$$

$$\rightarrow C_6H_5CH(OR)-CH_2-CH_2-CH(OR)-C_6H_5\text{, where: } R=OCH_3,\ OC_2H_5.$$

The methyl and ethyl ethers of diphenylbutynediol were prepared by Mamedov's method from the corresponding alcohols and diphenylbutynediol with m.p. 140-142°, synthesized by Iotsich's method [11] from dimagnesiumdibromo acetylene and acetaldehyde. It should be noted that when following the instructions recommended by Mamedov for the synthesis of diphenylbutyne diol, we were able to obtain a 70% yield only by using a smaller amount of sulfuric acid, and when prolonging the duration of the reaction.

The ethers of diphenylbutynediol prepared by us were identical with those previously described by Mamedov; however, when the ethers were very carefully dried and subjected to repeated vacuum fractionation, we were unable to get a negative reaction with the organomagnesium compound, pointing to contamination with partial ethers. The ethers of diphenylbutynediol prepared by us were therefore reacted with dialkyl magnesium halides. By this means the partial ethers were precipitated as magnesium alcoholates while the full ethers remained in solution. A similar purification was previously undertaken by Yu. S. Zalkind and I. P. Khazova [12] when synthesizing the ethers of tetramethylbutynediol.

After decomposing the organomagnesium complex we isolated a faint-yellow liquid with a pleasant odor corresponding to the partial ethyl ether of diphenylbutynediol (II).

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* Deceased.

$C_6H_5CH(OC_2H_5){-}C{\equiv}C{-}CHOH{-}C_6H_5$ (II). $C_6H_5CH(OCH_3){-}C{\equiv}C{-}CH(OCH_3)C_6H_5$ (I).
$C_6H_5CH(OC_2H_5){-}C{\equiv}C{-}CH(OC_2H_5)C_6H_5$ (III)

The full methyl (I) and ethyl (III) ethers prepared by us by the above procedure are oily liquids with a faint-yellow color.

The chemically pure full ethers of diphenylbutynediol react with potassium permanganate and are oxidized to the corresponding alkoxy acid and to benzoid acid. In an acid medium they are hydrolyzed to form the original glycol.

Bromination of the ethers results in addition at the triple bond of only two bromine atoms with formation of the corresponding dibromides which are distinguished by exceptional stability to the action of potassium permanganate solution, bromine water and hydrogen.

The full ethers of diphenylbutenediol and diphenylbutanediol were prepared by hydrogenation of the corresponding ethers of diphenylbutynediol in presence of colloidal palladium and platinum black. The ethers of both the olefinic and the saturated series were isolated.

The ethers of diphenylbutenediol are oily, light-yellow liquids, readily oxidized by potassium permanganate solution. They are at once decolorized by bromine water. The ethers obtained by addition of 4 atoms of hydrogen to the glycol molecule are likewise light-yellow, oily liquids.

It was established that in the hydrogenation of the ethers of diphenylbutynediol in identical conditions with the same amount of catalyst, the full methyl ether is hydrogenated more rapidly than the full ethyl ether.

EXPERIMENTAL

I. Synthesis of Methyl and Ethyl Ethers of Diphenylbutynediol

To diphenylbutynediol with m.p. 140-142°, obtained by the Iotsich method, was added the alcohol containing a small amount of concentrated sulfuric acid (s.g. 1.83). After heating and stirring, the reaction mass was neutralized with anhydrous sodium carbonate. The reaction products were extracted with ether, washed with water, dried with sodium sulfate and vacuum-distilled. Results are in Table 1.

TABLE 1

No. of expt.	Amount				duration of reaction in hrs	Temperature		Yield of ether	
	of diphenylbutynediol (in g)	CH_3OH (in ml)	C_2H_5OH (in ml)	H_2SO_4 (in ml)		Experimental (in °)	Of boiling of ether	(in g)	(in %)
1	10	50	–	2.5	24	60-65	172-175/3 mm	8.0	71.6
2	10	50	–	3.0	24	60-65	180-184/4 mm	8.0	71.6
3	5	–	40	2.0	24	70-80	185-190/5 mm	4.7	76.17
4	10	–	50	5.0	15	70-80	182-190/5 mm	3.85	31.20

II. Separation of the Mixture of Full and Partial Ethers of Diphenylbutynediol

The percentage of partial ether in the mixture was determined and the mixture dissolved in three times the volume of dry ether; dropwise addition, under continuous stirring, was then made to the cooled organomagnesium compound. At the termination of the reaction the ethereal solution contained the full ether and the precipitate contained the partial ether in the form of an organomagnesium complex. The product obtained after decomposition of the organomagnesium complex of the partial methyl ether of diphenylbutynediol was not investigated, due to the minute amount. From the ethereal layer was isolated a fraction with b.p. 168-170° at 2 mm, corresponding to the full methyl ether of diphenylbutynediol. In similar purification of the ethyl ether of diphenylbutynediol, a fraction with b.p. 193-194° at 3.5 mm was isolated which corresponded to the partial ethyl ether; from the ethereal layer was isolated a fraction with b.p. 188-190° at 2 mm, corresponding to the full ethyl ether of diphenylbutynediol.

Examination of the 168-170° (2 mm) fraction. (Full methyl ether of diphenylbutynediol.

0.2005 g substance: 0.5950 g CO_2; 0.1225 g H_2O. 0.2101 g substance: 0.6233 g CO_2; 0.1314 g H_2O. Found %: C 80.93, 80.91; H 6.83, 6.99. $C_{18}H_{18}O_2$. Calculated %: C 81.20; H 6.76.

Zeisel determination of methoxy groups: 0.1002 g substance: 0.1760 g AgI. Found %: CH_3O 23.24. $C_{18}H_{18}O_2$. Calculated %: CH_3O 23.31.

Determination of specific gravity and molecular refractinn: d_{20}^{20} 1.0800; n_D^{20} 1.5600. Found: MR_D 79.64. $C_{18}H_{18}O_2$. Calculated: MR_D 79.41.

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Examination of 193-194° (3.5 mm) fraction. (Partial ethyl ether of diphenylbutynediol.)

0.2521 g substance: 0.7500 g CO_2; 0.1590 g H_2O. 0.2201 g substance: 0.6538 g CO_2; 0.1369 g H_2O. Found %: C 81.13, 81.01; H 7.05, 6.96. $C_{18}H_{18}O_2$. Calculated %: C 81.20; H 6.77.

Molecular weight determination: 0.1505 g substance: 29.5 g C_6H_6: Δt 0.10°. 0.2003 g substance. 19.8 g C_6H_6: Δt 0.20°. Found: M 260.2; 258. $C_{18}H_{18}O_2$. Calculated: M 266.

Zeisel determination of ethyoxyl groups: 0.1362 g substance: 0.1200 g AgI. Found %: C_2H_5O 16.89. $C_{18}H_{18}O_2$ Calculated %: C_2H_5O. 16.92.

Specific gravity and molecular refraction: d_{20}^{20} 1.0608; n_D^{20} 1.5425. Found: MR_D 78.91. $C_{18}H_{18}O_2$ Calculated MR_D 79.29.

Terentev determination of hydroxyl groups: 0.0720 g substance: 6.2 ml CH_4 (18°, 763 mm). Found: ν_0 CH_4 5.7 ml; % OH 5.87. $C_{18}H_{17}O(OH)$. Calculated: CH_4 6.0 ml; % OH 6.39.

The substance with b.p. 193-194° at 3.5 mm corresponds to the partial ethyl ether of diphenylbutynediol and is a light-yellow liquid with a pleasant odor. It dissolves readily in organic solvents. Hydrolysis of the ether with 10% sulfuric acid gives the original glycol.

Examination of the fraction with b.p. 188-190° at 2 mm. (Full ethyl ether of diphenylbutynediol).

0.2101 g substance: 0.6280 g CO_2; 0.1421 g H_2O. 0.2302 g substance: 0.6880 g CO_2; 0.1570 g H_2O. Found %: C 81.52, 81.51; H 7.51, 7.63. $C_{20}H_{22}O_2$. Calculated %: C 81.63; H 7.48.

Molecular weight determination: 0.1005 g substance; 11.40 g C_6H_6; Δt 0.15°. 0.2001 g substance; 12.30 C_6H_6: Δt 0.28°. Found: M 299.7, 296.3. $C_{20}H_{22}O_2$. Calculated: M 294.

Zeisel determination of ethoxyl groups: 0.2150 g substance: 0.3401 g AgI. Found %: C_2H_5O 30.32. $C_{20}H_{22}O_2$. Calculated %: C_2H_5O 30.61.

Specific gravity and molecular refraction: d_{20}^{20} 1.0469; n_D^{20} 1.5455. Found: MR_D 88.85. $C_{20}H_{22}O_2$. Calculated: MR_D 88.64.

The full ethyl ether of diphenylbutynediol is a light-yellow oily liquid with a floral odor.

Oxidation of substance with b.p. 168-170° at 2 mm. 3 g of the full methyl ether of diphenylbutynediol was oxidized with 4.7 g potassium permanganate (calculated for four atoms of oxygen per molecule of ether) in presence of 0.5 g potassium carbonate. The oxidizing agent was added in the form of 1% solution dropwise with stirring at room temperature. Duration of oxidation was 3 hours. Ether extraction was performed at the conclusion of the reaction. No neutral products were identified. Benzoic acid with m.p. 121° came down from the filtrate after concentration and acidification with 10% sulfuric acid It did not depress the melting point of an authentic specimen of benzoic acid.

From the acids which were difficultly volatile in steam was isolated a yellowish viscous oil, part of which crystallized in the form of rods after prolonged standing. It was impossible, however, to determine the melting point because the crystals could not be isolated in the pure form. A portion of the obtained acid was converted into the silver salt via the ammonium salt.

0.2101 g salt: 0.3037 g CO_2; 0.0647 g H_2O; 0.0825 g Ag. 0.1521 g salt : 0.2197 g CO_2; 0.0476 H_2O; 0.0596 g Ag. Found %: C 39.42, 39.39; H 3.44, 3.50; Ag 39.26, 39.18. $C_9H_9O_3Ag$. Calculated %: C 39.58; H 3.30; Ag 39.53.

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$C_6H_5CH(OC_2H_5)-C{\equiv}C-CHOH-C_6H_5$ (II). $C_6H_5CH(OCH_3)-C{\equiv}C-CH(OCH_3)C_6H_5$ (I).

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The prepared silver salt corresponds to the salt of methoxyphenylacetic acid. According to the literature [13], this acid is a slowly solidifying oil.

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0.0592 g salt: 0.0899 g CO_2; 0.0183 g H_2O; 0.224 g Ag. Found %: C 41.41; H 3.45; Ag 37.84. $C_{10}H_{11}O_3Ag$. Calculated: C 41.83; H 3.83; Ag 37.60.

The acid corresponds to ethoxyphenylacetic acid. According to the literature [13], this acid is a viscous oil and forms a silver salt which does not darken in the air.

III. Bromination of the Full Methyl and Ethyl Ethers of Diphenylbutynediol

Into 2 g of the full methyl ether of diphenylbutynediol dissolved in 30 ml dry chloroform was run 12 ml 10% solution of bromine in dry chloroform (calculated for two atoms of bromine per molecule of the ether). Bromination required 2.5 hours at a temperature of 20-30°.

No evolution of hydrogen iodide was observed. Any bromine not entering into reaction was bound by washing with sodium carbonate solution and then with water. After drying the ether-chloroform solution and distilling off the solvents, a liquid was obtained which crystallized on standing. It melted at 145-146° after recrystallization from ethyl alcohol.

When bromination was carried out with the amount of bromine calculated for four atoms of bromine per molecule of glycol ether, a similar product with m.p. 145-146° was isolated in the form of fine white crystals.

0.1398 g substance: 0.1223 g AgBr. Found %: Br 37.23. $C_{18}H_{18}O_2Br_2$. Calculated %: Br 37.53.

Molecular weight determination: 0.0690 g substance; 16.50 g C_6H_6: Δt 0.05°. 0.0722 g substance: 17.55 g C_6H_6: Δt 0.05°. Found: M 427.0, 420.0. $C_{18}H_{18}O_2Br_2$. Calculated: M 425.8.

Zeisel determination of methoxyl groups: 0.0638 g substance: 0.0670 g AgI. Found %: CH_3O 13.89. $C_{18}H_{18}O_2Br_2$. Calculated %: CH_3O 14.58.

The obtained dibromide was readily soluble in benzene and chloroform and did not decolorize bromine water and potassium permanganate solution. By heating it with zinc dust in alcoholic solution for 12 hours there was obtained (in addition to unchanged dibromide) a small amount of the corresponding ether.

Bromination of the full ethyl ether was effected in similar condition. Reaction with both two and four atoms of bromine gave one and the same liquid dibromide which decomposed when distilled in vacuum. Analysis was therefore performed immediately after drying and driving off the solvent.

0.1116 g substance: 0.0946 g AgBr. 0.1564 g substance: 0.1308 g AgBr. Found %: Br 36.07, 35.59. $C_{20}H_{22}O_2Br_2$. Calculated %: Br 35.22.

Molecular weight determination: 0.1824 g substance; 20.10 g C_6H_6; Δt 0.10. Found: M 462.8. $C_{20}H_{22}O_2Br_2$. Calculated: M 453.8.

The obtained liquid dibromide does not decolorize bromine water or potassium permanganate solution.

IV. Hydrogenation of the Methyl and Ethyl Ethers of Diphenylbutynediol in Presence of Colloidal Palladium and Platinum Black

Colloidal palladium was prepared by Paal's method, platinum black by Loew's method [15]. The hydrogenation catalysts were always freshly prepared; their activity was tested by hydrogenation of tetramethylbutynediol. Electrolytic hydrogen was used.

The hydrogenation procedure and the isolation and purification of the products have been described in numerous papers by Yu. S. Zalkind and co-workers [16, 17, 18, 19, 20].

The hydrogenation products were investigated after addition of two atoms of hydrogen per molecule of ether and also after addition of four atoms of hydrogen.

1) Examination of product of hydrogenation of the full methyl ether of diphenylbutynediol.

a) After addition of two atoms of hydrogen (colloidal palladium catalyst). The product of incomplete hydrogenation of the methyl ether of diphenylbutynediol is a light-yellow, fairly mobile liquid with a rather pleasant odor, b.p. 210-211° at 5 mm, readily soluble in organic solvents. It energetically decolorizes bromine water and potassium permanganate solution. No hydroxyl groups were detected by the Chugaev-Tserevitinov method.

0.1302 g substance: 0.3840 g CO_2; 0.0889 g H_2O. 0.1221 g substance: 0.3603 g CO_2; 0.0836 g H_2O. Found %: C 80.43, 80.47; H 7.64, 7.66. $C_{18}H_{20}O_2$. Calculated %: C 80.60; H 7.46.

Molecular weight determination: 0.1542 g substance; 14.20 g C_6H_6: Δt 0.21°. Found: M 263.7. $C_{18}H_{20}O_2$. Calculated: M 268.0.

Zeisel determination of methoxyl groups: 0.1012 g substance: 0.1750 g AgI. Found %: CH_3O 22.88. $C_{18}H_{20}O_2$. Calculated %: CH_3O 23.13.

Specific gravity and molecular refraction: d_{20}^{20} 1.0555; n_D^{20} 1.5570. Found: MR_D 81.00. $C_{18}H_{20}O_2$. Calculated: MR_D 80.96.

Oxidation of the product of hydrogenation with b.p. 210-211° at 5 mm. 3 g of hydrogenation product was oxidized with 4.7 g potassium permanganate (calculated for four atoms of oxygen per molecule of hydrogenation product) in the form of 1% aqueous solution. Oxidation was first performed under cooling with iced water and later at room temperature. The reaction period was 2½ hours.

The oxidation products were isolated by the usual procedure and corresponded to benzoic and methoxyphenylacetic acids (see oxidation of full methyl ether of diphenylbutynediol).

b) After addition of four hydrogen atoms (platinum black catalyst). The product of full hydrogenation of the full methyl ether is a light-yellow, mobile liquid with b.p. 150-155° at 2 mm; it has a very faint odor; it is readily soluble in organic solvents. It does not decolorize bromine water or potassium permanganate solution.

0.1542 g substance: 0.4513 g CO_2; 0.1135 g H_2O. 0.2031 g substance: 0.5948 g CO_2; 0.1501 g H_2O. Found %: C 79.81, 79.86; H 8.23, 8.27. $C_{18}H_{22}O_2$. Calculated %: C 80.00; H 8.14.

Molecular weight determination: 0.2411 g substance; 23.80 g C_6H_6: Δt 0.19°. Found: M 271.9. $C_{18}H_{22}O_2$. Calculated: M 270.0.

Zeisel determination of methoxyl groups: 0.1620 g substance: 0.2781 g AgI. Found %: CH_3O 22.71. $C_{18}H_{22}O_2$. Calculated %: CH_3O 22.96.

Specific gravity and molecular refraction: d_{20}^{20} 1.0340; n_D^{20} 1.5380. Found: MR_D 81.65. $C_{18}H_{22}O_2$. Calculated: MR_D 81.43.

2) Investigation of the product of hydrogenation of the full ethyl ether.

a) After addition of two atoms of hydrogen (colloidal palladium catalyst). The product of incomplete reduction of the ethyl ether of diphenylbutynediol is a light yellow liquid boiling at 173-174° at 3 mm; readily soluble in organic solvents. It decolorizes bromine water and potassium permanganate solution.

0.1531 g substance: 0.4541 g CO_2; 0.1133 g H_2O. Found %: C 80.89; H 8.28. $C_{20}H_{24}O_2$. Calculated %: C 81.08; H 8.11.

Molecular weight determination: 0.1251 g substance; 14.50 g C_6H_6: Δt 0.15°. Found: M 293.3. $C_{20}H_{24}O_2$. Calculated: M 296.0.

Determination of ethoxyl groups (Zeisel): 0.1849 g substance: 0.2920 g AgI. Found %: C_2H_5O 30.26. $C_{20}H_{24}O_2$. Calculated %: C_2H_5O 30.41.

Specific gravity and molecular refraction: d_{20}^{20} 1.0260; n_D^{20} 1.5388. Found: MR_D 90.35. $C_{20}H_{24}O_2$. Calculated: MR_D 90.20.

Oxidation of the partial hydrogenation product was performed as for the oxidation of the full ethyl ether of diphenylbutynediol. The reaction period was 3 hours. Analogous products were isolated: benzoic acid and ethoxyphenylacetic acid which was characterized as the silver salt.

0.1425 g substance: 0.2179 g CO_2: 0.0508 g H_2O; 0.0534 g Ag. Found %: C 41.70; H 3.98; Ag 37.47. $C_{10}H_{11}O_3Ag$. Calculated %: C 41.83; H 3.83; Ag 37.63.

b) After addition of four hydrogen atoms (platinum black catalyst). The product of full hydrogenation of the ethyl ether is a light-yellow liquid boiling at 120-124° at 3 mm. It does not decolorize bromine water and potassium permanganate solution.

0.1331 g substance: 0.3921 g CO_2; 0.1059 g H_2O. Found %: C 80.34; H 8.84. $C_{20}H_{26}O_2$. Calculated %: C 80.54; H 8.72.

Ethoxyl groups determination (Zeisel): 0.1542 g substance: 0.2420 g AgI. Found %: C_2H_5O 30.07. $C_{20}H_{26}O_2$. Calculated %: C_2H_5O 30.20.

Specific gravity and molecular refraction: d_{20}^{20} 1.0210. n_D^{20} 1.5380. Found: MR_D 91.30. $C_{20}H_{26}O_2$. Calculated: MR_D 90.67.

SUMMARY

1. The following compounds were synthesized and characterized: 1,4-Diphenyl-1,4-dimethoxybutyne-2; 1,4-diphenyl-1,4-dimethoxybutene-2; 1,4-diphenyl-1,4-dimethoxybutane; 1,4-diphenyl-1,4-diethoxybutyne-2; 1,4-diphenyl-1,4-diethoxybutene-2; 1,4-diphenyl-1,4-diethoxybutane; and 1,4-diphenyl-1-ethoxybutyne-2-ol-4.

2. The bromination of the methyl and ethyl ethers of diphenylbutynediol was investigated. Bromine was found to combine in the proportion of two atoms per molecule of the glycol.

3. The dibromides prepared by bromination of the methyl and ethyl ethers of diphenylbutynediol were isolated and characterized.

4. Hydrogenation of the methyl and ethyl ethers of diphenylbutynediol with colloidal platinum gives the corresponding ethers of the olefinic series, and hydrogenation with platinum black gives the ethers of the saturated series.

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*** See Consultants Bureau English translation, p. 2309.

**** See Consultants Bureau English translation, p. 923.

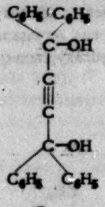
THE REACTION OF 2,5-DIPHENYLHEXYNE-3-DIOL-2,5 (SYMMETRICAL DIMETHYLPHENYLBUTYNEDIOL) WITH PHENOL IN PRESENCE OF SULFANILIC ACID

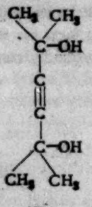
Yu. S. Zalkind* and G. M. Kharkharova

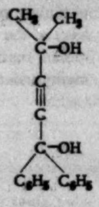
Yu. S. Zalkind, V. K. Teterin and S. G. Kuznetsov [1] were the first to show that acetylenic γ-glycols are capable of condensing with phenol in presence of acid catalysts. It was established that tetraphenylbutynediol (I), which only contains aromatic radicals attached to the hydroxyl carbon, condenses with phenol in presence of sulfanilic acid to form derivatives of benzfulvene, dihydrofuran and indenechroman.

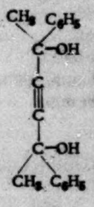
Tetramethylbutynediol (II), containing only aliphatic radicals [2], and unsymmetrical dimethyldiphenylbutynediol (III), whose methyl groups are concentrated at one carbon atom and the phenyl groups at another [3], react with phenol predominantly with formation of dihydrofuran derivatives.

The symmetrical dimethyldiphenylbutynediol which we have investigated contains both aliphatic and aromatic radicals at the same tertiary alcoholic carbon atom (IV).


(I)


(II)


(III)


(IV)

Both of its isomers react with phenol in presence of sulfanilic acid in a medium of dry benzene to form identical condensation products. The reaction proceeds fairly readily with loss of about two molecules of water per molecule of glycol and is completed in the course of an hour.

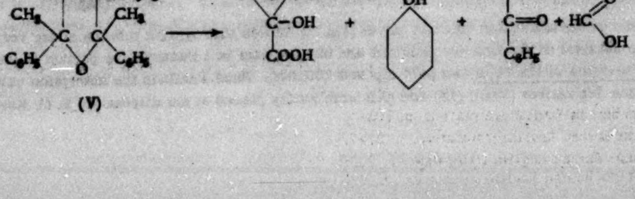
After steam-distillation of the excess of phenol and solvent, a low-melting oil was obtained from which, not without difficulty, we succeeded in isolating six substances with a total yield of about 70%.

The properties of these substances, and also their ultraviolet and visible spectral curves (Figure 1) showed that to none of these compounds could a structure close to that of the original glycol be assigned.

Three of our isolated products appear to have structures similar to the products of condensation of tetraphenylbutynediol with phenol [1].

A light-yellow oil obtained in a yield of about 6% was vacuum-distilled (5-10 mm) at 230-260°. In elementary analysis and molecular weight it corresponded to $C_{24}H_{22}O_2$, indicating the addition of one molecule of phenol to glycol with elimination of a molecule of water.

The substance did not contain hydroxyl groups and did not react with an alcoholic solution of semicarbazide. When digested with hydrogen iodide it split up with formation of phenol, demonstrating the presence of a phenoxy group. On the basis of these data the substance was assigned the structure of 2,5-dimethyl-2,5-diphenyl-3-phenoxydihydrofuran-2,5 (V).


(V)

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* Deceased.

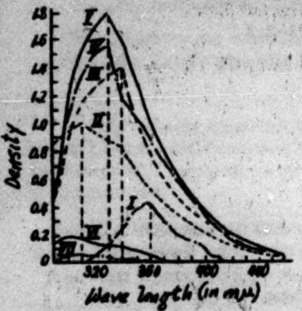


Fig. 1. Curves of absorption spectra of isomers of the original glycol and of products of their condensation with phenol.

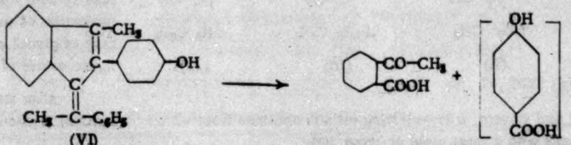
I - lemon-yellow substance with m.p. 220-220.5°;
II - light-yellow substance with m.p. 154-160°;
III - orange substance with m.p. 80-82°;
IV - yellow substance with m.p. 125-127°;
V - yellow substance with m.p. about 50°;
VI - dimethyldiphenylbutynediol with m.p. 160°;
VII - dimethyldiphenylbutynediol with m.p. 125-127°.

The structure was confirmed by oxidation with potassium permanganate in acetone [1]. Oxidation did not proceed to completion, part of the substance being recovered unchanged. Acetophenone and phenol were found in the neutral products of oxidation; formic and methylphenylglycollic acids in the acidic products.

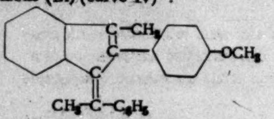
The composition of the oxidation products thus confirmed the proposed structural formula.

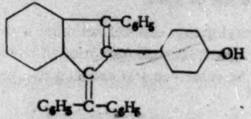
The yellow crystalline substance with m.p. 125-127° corresponded in composition to $C_{24}H_{20}O$, pointing to addition to the glycol of one molecule of phenol with elimination of two molecules of water. The yield was 15-16%.

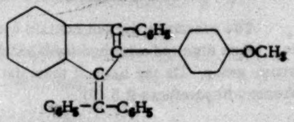
Its color (absorption maximum at 330 mμ) (Fig. 1, curve IV), the ability to decolorize bromine water and potassium permanganate solution, the formation of a crimson coloration in concentrated sulfuric acid all indicated that this compound contained the benzfulvene group. The Chugaev-Tserevitinov reaction showed the presence of one hydroxyl group. Its ability to form a phenolate pointed to its phenolic character. On the basis of the foreoing facts the structure can be assumed to be 1-methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene (VI):


(VI)

This structure was confirmed by oxidation. Among the oxidation products were found acetophenone, acetylbenzoic acid and, apparently, phthalic acid; p-hydroxy-benzoic acid was decomposed in these conditions. The isolated oxidation products were not inconsistent with the proposed structure. Support for the structure (VI) is also provided by a comparison of its spectral curve (curve I, Fig. 1) with the curves of its methoxy derivative (VII) (Fig. 2, curve II), which was prepared by reaction of anisole with 2,5-diphenylhexyne-3-diol-2,5 and with the curves of two compounds whose structures are authenticated: 1-diphenylmethylene-2-(p-hydroxyphenyl)-3-phenylindene (VIII) (curve III) and 2-diphenylmethylene-2-(p-methoxyphenyl)-3-phenylindene (IX) (curve IV)*.


(VII)


(VIII)


(IX)

Comparison of the absorption spectral curves (Fig. 2) showed that all four substances are very similar in structure. The maxima of the first two (330 mμ and 320 mμ) are in a shorter wave portion of the spectrum compared to the maxima of the other two (370 mμ and 360 mμ). Such a shift in the absorption band was also to be expected after replacement of two methyl groups by phenyl groups.

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* The benzfulvene derivatives (VIII), (IX) and (XI) were kindly placed at our disposal by S. G. Kuznetsov.

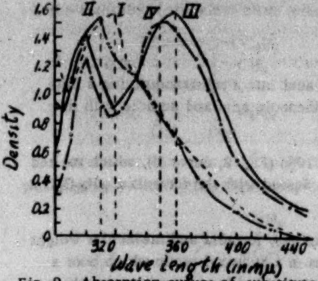


Fig. 2. Absorption curves of substituted benzfulvenes.
I. 1-methylphenylmethylene-3-(p-hydroxyphenyl)-3-methylindene (yellow substance with m.p. 125-127°)(formula VI); II. 1-methylphenylmethylene-2-(p-methoxyphenyl)-3-methylindene (formula VII); III. 1-diphenylmethylene-2-(p-hydroxyphenyl)-3-phenylindene (formula VIII); IV. 2-diphenylmethylene-2-(p-methoxyphenyl)-3-phenylindene (formula IX).

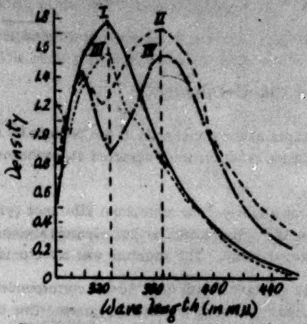
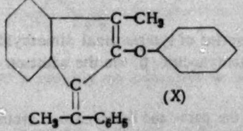


Fig. 3. Absorption spectra of some indene derivatives.
I. 1-methylphenylmethylene-2-phenoxy-3-methylindene (formula X); II. 1-diphenylmethylene-2-phenoxy-3-phenylindene (formula XI); III. 1-methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene (formula VI); IV. 1-diphenylmethylene-2-(p-hydroxyphenyl)-3-phenylindene (formula VIII).

The absorption curves of the ethers (Fig. 2, curves II and IV) and their oxy compounds (Fig. 2, curves I and III) are similar in character, but their maxima are shifted to the left.

The yellow amorphous substance obtained in a yield of 6-10% melted at about 50°. It is apparently the isomeric 1-methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene (VI). Its absorption curve is similar to the curve of 1-methylphenylmethylene-(2-p-hydroxyphenyl)-3-methylindene (Fig. 1, curves IV and V).

The maxima of these curves are at the same wave length (330 mμ). The absence of hydroxyl, the presence of a phenoxy group and the red coloration in concentrated sulfuric acid enable us provisionally to assign to it the structure of 1-methylphenylmethylene-2-phenyloxy-3-methylindene (X).


(X)

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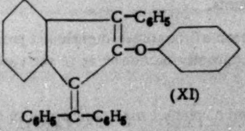
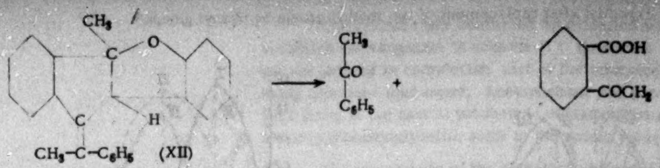

(XI)

All the curves plotted in Figure 3 are similar in character, and thus point to similar structures of these compounds.

The remaining substances isolated from the reaction mass differ in properties both from one another and from the above-noted products. Their absorption curves (Fig. 1, curves I, II, and III) differ both in form and in position of maxima (360, 310, 340 mμ).

One of these is in the form of lemon-yellow crystals (Fig. 1, curve I) with m.p. 220-220.5°, yield 1.5%.

The analytical data and molecular weight agree with the formula $C_{24}H_{20}O$. This compound is the most deeply colored (maximum at 360 mμ) (Fig. 1, curve I). It is sparingly soluble in concentrated sulfuric acid and almost insoluble in all organic solvents. Its solutions do not exhibit the fluorescence which is characteristic of indenechroman derivatives. [1]. The absence of hydroxyl, carbonyl and phenoxy groups suggest that the oxygen in the molecule is present in a ring. This compound may have been formed by addition of phenol in the ortho-position followed by closure of the cumarone ring with formation of 2-methyl-1'-methylphenylmethylene-(2', 3': 2,3-indeno)cumaran (XII):

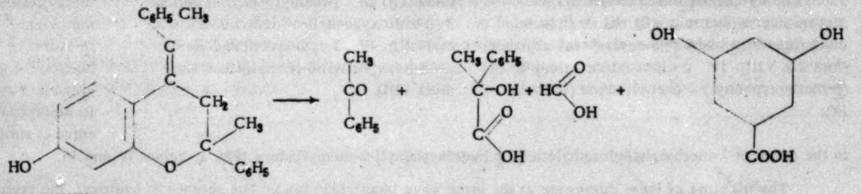

CH$_3$
C
O
H
C
CH$_3$–C–C$_6$H$_5$
CH$_3$
CO
C$_6$H$_5$
COOH
COCH$_3$

(XII)

Such a structure explains the conversion of the product by hydriodic acid into a substance giving a blue fluorescence. In the oxidation products were detected acetophenone, acetylbenzoic acid and an acid with m.p. 115-118°.

Another product was a light-yellow amorphous substance (yield up to 10%) (Fig. 2, curve II), which melted with decomposition at 154-160°. Its molecular and elementary composition agreed with the formula $C_{72}H_{69}O_3$. It contained a phenolic hydroxyl group. The structure was not elucidated.

Finally, the orange substance with m.p. 80-82° corresponded in elementary formula and molecular weight to $C_{24}H_{22}O_2$. It did not contain phenoxy or carbonyl groups. One oxygen was in a hydroxyl group which bore a phenolic character. Exploratory oxidation of the substance showed that the neutral products contain acetophenone and the acid ones (in addition to formic acid and methylphenylglycollic acid), an acid which resembled 2,4-dihydroxybenzoic acid in being easily brominated (bromide with m.p. 80-83°) and in giving a red coloration with iron chloride. Its silver salt easily decomposed. The evidence did not justify assigning to it a dihydrofuran structure. It is possibly 2-methylphenyl-4-methylphenylmethylene-7-hydroxy-2,3-dihydrobenzpyran (XIII):


C$_6$H$_5$ CH$_3$
C
C
CH$_2$
CH$_3$
C
O
C$_6$H$_5$
HO
CH$_3$
CO
C$_6$H$_5$
CH$_3$ C$_6$H$_5$
C–OH
C
O
OH
HC
O
OH
OH
OH
COOH

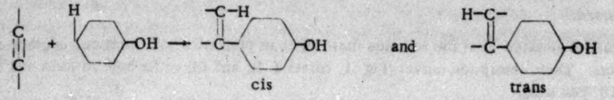
(XIII)

Oxidation of such a compound would result in the occurrence of 2,4-dihydroxybenzoic acid among the oxidation products.

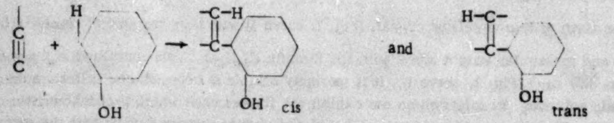
Formation of the above-mentioned products of condensation of symmetrical dimethyldiphenylbutynediol with phenol apparently proceeds, as in the case of tetraphenylbutynediol (I), via the addition of phenol at the triple bond.

Addition of phenol may take place in three ways: at the para- and ortho-carbon atom (since there is a higher electronic density at these points) and at the hydroxyl oxygen which has a free electron pair:

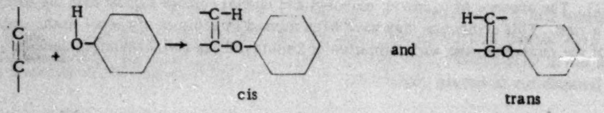
(I)


C
C
H
OH
–C–H
–C–
OH
and
H–C–
–C–
OH
cis
trans

(II)

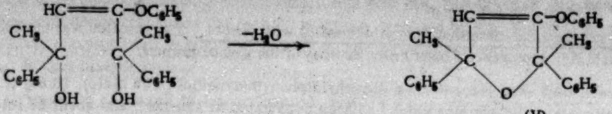

C
C
H
OH
–C–H
–C–
OH
cis
and
H–C–
–C–
OH
trans

(III)


C
C
H
O
–C–H
–C–O–
and
H–C–
–C–O–
cis
trans

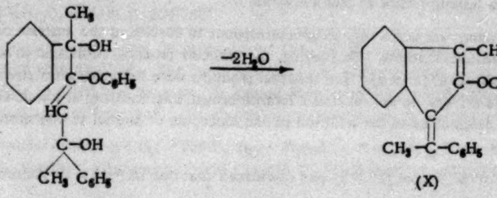
The intermediate products of addition of phenol to the glycol can exist in cis- and trans-forms. In the reaction conditions these products tend to pass into the more stable cyclic compounds. The cis-form is susceptible to cyclization to γ-oxides due to the proximity of the two hydroxyl groups.

Thus, the formation of 2,5-dimethyl-2,5-diphenyl-3-phenoxydihydrofuran-2,5 (V) would appear to proceed via the cis-form of the vinyl ether (product of addition of phenol at the triple bond of the glycol; scheme III):



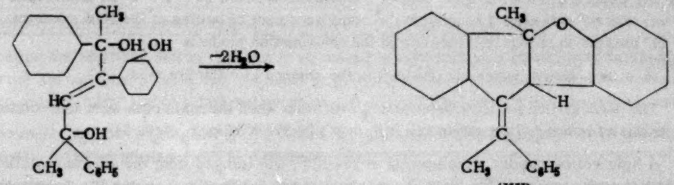
(V)

1-Methylphenylmethylene-2-phenoxy-3-methylindene (X) is possibly formed via the trans-form of the vinyl ether:



(X)

1-Methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene (VI) is derived from the trans-form of the products of addition of phenol in the p-position (scheme II). When addition occurs in the o-position, closure of both the indene and cumarone ring takes place according to the scheme:



(XII)

The trans-form is possibly the intermediate in formation of products of dehydration, of pyran derivatives, of resins, etc.

Closure of the pyran ring is possible at the expense of the double bond of the phenolic nucleus activated by the presence of the phenolic hydroxyl.

Consequently the reaction of phenol with symmetrical dimethyldiphenylbutynediol gives products some of which are similar in structure to those resulting from the phenol-tetraphenylbutynediol condensation and some of which are different in structure.

It transpired that the yield of products of transformation of the cis-form in the case of tetraphenylbutynediol is 3%, that in the case of unsymmetrical dimethyldiphenylbutynediol is up to 85%, that of symmetrical dimethyldiphenylbutynediol is 6.10%, and that of tetramethylbutynediol is about 40%.

We see, therefore, that the largest amount of cis-derived products is formed in the case of the unsymmetrical glycol molecule. In the symmetrical glycols the replacement of alkyl groups by aryls leads to a drop in yield of these transformation products.

On the basis of the foregoing observations it follows that the behavior of acetylenic γ-glycols largely depends on their structure, i.e., on the character and arrangement of the radicals attached to the carbon atom linked to the hydroxyl group.

The joint presence of methyl and phenyl groups at one carbon atom facilitates reaction in various directions. These features have been confirmed in work with other compounds [6].

EXPERIMENTAL

Preparation of 2,5-diphenylhexyne-3-diol-2,5 (symm. dimethyldiphenylbutynediol) (IV). The glycol was prepared, as described by Iotsich [4], by the action of acetophenone on acetylene bismagnesium bromide in a medium of dry ether. The inactive steroisomers (l and d + l) of the glycol were resolved by fractional crystallization from ether and alcohol [4]. The total yield of glycol was about 80%; that of the isomer with m.p. 163° was 32%, that of the isomer with m.p. 125-127° was 48%.

Condensation of symmetrical dimethyldiphenylbutynediol with phenol. The reaction was conducted in a V.K. Teterin apparatus [1,5]. It proceeded identically for both of the glycol isomers.

In a round-bottomed flask were placed 13.3 g dimethyldiphenylbutynediol (0.05 mole), 18.8 g phenol (0.2 mole), 0.2 g sulfanilic acid (0.0012 mole) which had been dehydrated at 120-130°, and about 28 ml dry benzene, the latter being the amount calculated to prevent the temperature of the reaction mass from rising above 91°. The mixture was boiled for about an hour. With progressive elimination of water, the color of the reaction mass changed from lemon-yellow to reddish-brown.

A total of 1.67 ml water was given off, which corresponds to 80-85% of the amount calculated for two molecules of water per molecule of glycol. On cooling, the reaction products remained in solution. The precipitate consisted of sulfanilic acid (0.18 g). The reaction products were isolated, after steam-distillation of the excess of phenol and the solvent, in the form of a reddish-brown mass melting at about 40°. The weight of products (17.0 g) roughly corresponded to the addition of one molecule of phenol to one molecule of symm. dimethyldiphenylbutynediol.

The amount of unreacted phenol (13.3 g) also confirmed that one molecule of phenol had reacted.

A total of 880 ml condensation product was obtained. Test with 20 ml sample: 1.06 g tribromphenol. Amount of phenol entering into reaction: found 5.67; calculated 4.7.

The reaction velocity is profoundly influenced by the boiling temperature of the reaction mixture. Hardly any water is eliminated if the boiling temperature is below 86°. At 86° an appreciable amount of water was split off only after 2 hours from the commencement of boiling of the flask contents. Heating at above 91° resulted in serious resinification of the condensation products.

No elimination of water was observed in the absence of sulfanilic acid.

The condensation products were treated with ether when the main bulk went into solution, leaving a small residue of lemon-yellow substances with m.p. 220-220.5° (Fig. 1, curve 1).

A light-yellow powder, decomposing at 154-160°, was isolated from the ethereal solution by fractional precipitation with gasoline. The yield of the substance was 8-10% (Fig. 1, curve II). Evaporation of the filtrate over a long period of time led to separation, first, of an amorphous, orange substance (yield 8-20%), which after purification had m.p. 80-82° (Fig. 1, curve III); this was followed by a yellow crystalline substance (16-17%) with m.p. 125-127° (Fig. 1, curve IV). The residue was fractionated in vacuum to give an oil distilling at 230-260° (5-10 mm) in yield of 6% and an amorphous residue in the flask with m.p. about 50° (Fig. 1, curve V).

The absorption spectra of these substances were examined in a Beckmann spectrophotometer, using 96% ethyl alcohol as solvent. The concentration of the solution was 0.1 g per liter.

1) 2-Methyl-1'-methylphenylmethylene-(2',3':2,3-indeno)cumaran (XII). Beautiful lemon-yellow, tetrahedral prisms (yield 1.5%) with m.p. 220-220.5° (from benzene), difficultly soluble in nearly all organic solvents, in concentrated alkalis and acids. It has two extinctions in polarized light. The absorption maximum is at 360mμ (Fig. 1, curve I). This substance could be separated from the main bulk of glycol-phenol condensation products because of its difficult solubility in ether.

0.1061 g substance: 0.3478 g CO_2; 0.0613 g H_2O. Found %: C 89.39; H 6.45. $C_{24}H_{20}O$. Calculated %: C 88.9; H 6.2. 0.0166 g substance; 0.1626 g camphor: Δt 12.2°. Found: M 335.4. $C_{24}H_{20}O$. Calculated: M 324.3.

The absence of hydroxyl and carboxyl groups was demonstrated in the Chugaev-Tserevitinov reaction and in the reaction with alcoholic semicarbazide solution.

When treated with hydriodic acid, the substance did not regenerate phenol but was converted into another compound which dissolved readily in benzene and gave a blue fluorescence in benzene solution.

Oxidation. To a mixture of 1.0 g substance and 50 ml acetone heated on the water bath was added an acetone solution containing 1.3 g potassium permanganate. Oxidation was completed in 3 hours. The reaction mass was worked up in the usual manner [1]. The neutral products contained acetophenone and a small amount of original substance with m.p. 214-215°. The semicarbazone of the acetophenone melted at 196-199° and did not depress the melting point of an authentic specimen.

The acid products contained o-acetylbenzoic acid with m.p. 113-114° and an acid with m.p. 115-116° (in admixture with benzoic acid and the melting point was depressed by 2°). The acid possessed a pleasant honey-like odor; it crystallized in prisms difficultly soluble in water and very readily soluble in ether. The acid was not further investigated.

Analysis of the silver salt of o-acetylbenzoic acid:

0.0162 g substance: 0.0200 g Ag. 0.0200 g substance: 0.0078 g Ag. Found %: Ag 39.5, 39.0. $C_9H_7O_3Ag$. Calculated %: Ag 39.80.

2) Substance $C_{72}H_{60}O_3$ with m.p. 154-160°.

A light-yellow amorphous powder, decomposing at 154-160° (from alcohol), was isolated by precipitation from the ethereal solution with gasoline. The compound dissolved with difficulty in gasoline, methyl alcohol and ethyl alcohol, readily in ether and benzene. It formed phenolates with caustic alkalis. A brown coloration was developed in concentrated sulfuric acid. Its absorption maximum lies at 310 mμ (Fig. 1, curve II).

0.1025 g substance: 0.3372 g CO_2; 0.0589 g H_2O. Found %: C 89.46; H 6.43. $C_{24}H_{20}O$. Calculated %: C 89.00; H 6.2. 0.1901 g substance: 12 ml CH_4 (16.5°, 765.4 mm). $C_{24}H_{19}(OH)$. Calculated: CH_4 12.72 ml.

0.1270 g substance: 20.52 g benzene: Δt 0.08°. Found: M 1050. $C_{24}H_{20}O$. Calculated: M 324. $C_{72}H_{60}O_3$. Calculated: M 972.

Its structure was not elucidated.

3) 2-Methylphenyl-4-methylphenylmethylene-7-hydroxy-2,3-dihydrobenzpyran (XIII).

After purification the substance was in the form of an orange powder with m.p. 80-82°, readily soluble in ether, benzene, alcohol and acetone, soluble with difficulty in petroleum ether. It forms phenolates with caustic alkalis. It turns concentrated sulfuric acid a dark-yellow color. Absorption maximum at 340 mμ (Fig. 1, curve II).

0.1440 g substance: 0.4480 CO_2; 0.0836 g H_2O. Found %: C 84.54; H 6.39. $C_{24}H_{22}O_2$. Calculated %: C 84.21; H 6.41. 0.1897 g substance; 15.91 g benzene: Δt 0.134°.

Found: M 440 $C_{24}H_{22}O_2$. Calculated: M 342. 0.1001 g substance: 6.1 ml C_2H_6 (17°, 754.8 mm). $C_{24}H_{21}O(OH)$. Calculated: 6.55 ml C_2H_6.

Tests for carbonyl and phenoxy groups gave negative results.

Oxidation. 0.7 g substance was dissolved in 25 ml acetone. To the solution was added 0.95 g potassium permanganate in small portions. The temperature of the reaction mass was not raised to above 30°. Slight heating occurred during the oxidation. The reaction was complete in 2 1/2 hours.

The volatile neutral products contained acetophenone (no depression of melting point of its semicarbazone in admixture with acetophenone semicarbazone). The neutral products which distilled with difficulty in steam consisted of a resin from which we were unable to isolate any pure substances.

In the acid products were detected formic acid (it reduced a solution of mercuric chloride to mercurous chloride, and gave a readily decomposed silver salt) and methylphenylglycollic acid which readily broke down to acetophenone and formic acid The decomposition products of this acid were identified. There was also isolated an acid with m.p. 130-134° which gave a red coloration with iron chloride and was readily brominated to form a debromide with m.p. 80-83°. The silver salt of this acid readily decomposed.

4) 1-Methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene (VI).

The yellow crystalline substance isolated after precipitation of the products with m.p. 154-160° and 80-82° melted at 110-120°. The melting point rose to 125-127° after recrystallization from a mixture of ether and petroleum ether. The loss during purification was 30-40%.

The golden yellow hexagonal prisms of this compound were poorly soluble in petroleum ether, dilute alcohol and acids, highly soluble in ether, benzene, acetone, alcohol and glacial acetic acid. The absorption maximum in alcoholic solution lies at 330 mμ (Fig. 1, curve IV).

It gives a crimson coloration in concentrated sulfuric acid. With alkalis it forms phenolates difficultly soluble in organic solvents. It readily decolorizes bromine water and potassium permanganate solution. If forms a greenish-yellow solution in alcoholic alkali. The substance readily couples with diazotized p-nitroaniline.

0.1887 g substance: 0.6182 g CO_2, 0.0998 g H_2O. 0.1067 substance: 0.3324 g CO_2, 0.0548 g H_2O. Found %: C 88.44, 89.18; H 5.93, 6.04. $C_{24}H_{20}O$. Calculated %: C 83.90; H 6.22. 0.0507 g substance; 3.03 ml C_2H_6 (12°, 755.4 mm). 0.0704 g substance: 4.12 ml C_2H_6 (12°, 755.4 mm). $C_{24}H_{19}(OH)$. Calculated C_2H_6 3.6 ml, 4.86. 0.0358 g substance: 0.4305 g camphor: Δt 10.3°. Found: M 321. $C_{24}H_{20}O$. Calculated: M 324.

Oxidation. A solution of 3.6 g potassium permanganate in acetone was added to a solution of 2.8 g of the substance in 150 ml acetone. During oxidation the temperature rose to 30-40°.

Acetophenone was found in the neutral,volatile portion. The neutral difficultly volatile portion was a resin from which a pure compound could not be isolated.

The acid products contained o-phthalic acid with m.p. 143-145°.

0.0196 g substance: 0.0105 g Ag. Found %: Ag 53.40. $C_9H_4O_5Ag$. Calculated %: Ag 53.00.

Acetylbenzoic acid was also found with m.p. 112-118°. 0.0119 g substance; 0.0047 Ag. Found %: Ag 39.49. $C_9H_7O_3Ag$ Calculated %: Ag 39.85.

The proposed structure is supported by a comparison of the spectral curve of the compound (Fig. 3, max. 330 mμ) with the curves of indene derivatives.

5) 2,5-Dimethyl-2,5-diphenyl-3-phenoxydihydrofuran-2,5 (V).

Vacuum fractionation yielded a viscous light-yellow oil with b.p. 230-260° at 5-10 mm. Yield 5-6 %. The product was readily soluble in benzene, ether, petroleum ether, acetone and chloroform; sparingly soluble in methyl and ethyl alcohols. It does not react with alkalis and is insoluble in these. It decolorizes bromine water and turns concentrated sulfuric acid yellow; it does not contain hydroxyl groups.

0.2030 g substance: 0.6280 g CO_2; 0.1214 g H_2O. Found %: C 84.50; H 6.60. $C_{24}H_{22}O_2$. Calculated %: C 84.21; H 6.41. 0.0370 g substance; 0.2340 g camphor: Δt 19.7°. Found: M 334. $C_{24}H_{22}O_2$. Calculated: M 342.

Determination of the phenoxy group. A mixture of 0.4 g substance with 5 ml glacial acetic acid and 8 ml hydriodic acid was heated at the boil for 10 hours. After cooling, the reaction mass was worked up with sodium thiosulfate and sodium carbonate and distilled with steam. Tribromphenol was precipitated from the condensate in admixture with a red substance. After purification the tribromphenol caused no depression in a mixed melting point test. The melting of the mixture with authentic tribromphenol was 89-91°.

Oxidation. A solution of 1.0 g potassium permanganate in 50 ml acetone was added to a solution of 2.3 g substance in 50 ml acetone.

In the neutral volatile products were found acetophenone and phenol (identified respectively as the semicarbazone and tribromphenol). In the residue, after steam distillation, was found a resinous substance (m.p. about 40°).

From the acidic products were isolated formic acid (reduces mercuric chloride solution to calomel, gives a readily decomposed silver salt and a lead salt sparingly soluble in alcohol) and methylphenylglycollic acid with m.p. 59-63°.

The aqueous solution of the acid turned brown when shaken with manganese dioxide and decolorized completely when heated. Acetophenone and formic acid were found in the decomposition products.

0.0109 g substance: 0.0043 g Ag. Found %: Ag 39.4. $C_9H_9O_3Ag$. Calculated %: Ag 39.5.

6) 1-Methylphenylmethylene-2-phenoxy-3-methylindene (X).

An amorphous yellow substance melting at about 50° was found in the flask residue after distilling off the dihydrofuran derivative. It dissolves with difficulty in alcohol, readily in ether, benzene, gasoline, acetone and chloroform. Negative results were obtained in tests for hydroxyl and carbonyl groups. It was impossible to purify this substance completely from 2,4-dimethyl-2,5-diphenyl-3-phenoxydihydrofuran-2,5.

0.1130 g substance: 19.81 g benzene: Δt 0.088°. Found: M 344. $C_{24}H_{20}O$. Calculated: M 324. $C_{24}H_{22}O$. Calculated: M 342. 0.1553 g substance: 0.4932 g CO_2; 0.0908 g H_2O. 0.1462 g substance: 0.4674 g CO_2; 0.0860 g H_2O. Found %: C 85.45, 86.88; H 6.49, 6.49. $C_{24}H_{20}O$. Calculated %: C 88.90, H 6.20. $C_{24}H_{22}O_2$. Calculated %: C 84.21. H 6.41.

Comparison of its spectral absorption curve (maximum 330 mμ) with the curves for benzfulvene derivatives (Fig. 3) reveals a similarity of structure.

SUMMARY

1. It is shown that the reaction of both of the isomers of symm. dimethyldiphenylbutynediol with phenol in presence of sulfanilic acid proceeds in various directions with formation of no fewer than six compounds.

2. The following three condensation products are similar in structure to the products obtained from tetraphenylbutynediol and phenol: 2,5-dimethyl-2,5-diphenyl-3-phenoxydihydrofuran-2,5; 1-methylphenylmethylene-2-(p-hydroxyphenyl)-3-methylindene; and 1-methylphenylmethylene-2-phenoxy-3-methylindene.

3. It is shown that the products of addition of phenol at the triple bond can exist in cis- and trans-forms. In the case of symm. dimethyldiphenylbutynediol the trans-form predominates among the addition products.

4. The behavior of acetylenic γ-glycols during condensation with phenol depends on the character and arrangement of the radicals at the tertiary alcoholic carbon atom. An unsymmetrical structure of the acetylenic γ-glycols facilitates the formation of the cis-form of the intermediate products. The yield of condensation products derived from the cis-form decreases with replacement of methyl groups by phenyl groups.

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* See Consultants Bureau translation, p. 923.

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THE INHIBITING ACTION OF ALDEHYDES

V. S. Kemkhadze and S. A. Balezin

The protective action of inhibitors of acidic corrosion depends on the nature of the inhibitor, its molecular weight and structure, and its concentration, as well as on the concentration of the acid, temperature, etc. Inhibitors belonging to different groups of compounds give different coefficients of inhibiting action; moreover, the coefficients of inhibiting action are observed to fluctuate within a given class of inhibitors. An important practical and theoretical problem is the correlation of this variation with the molecular weight, structure, and other factors.

It has been pointed out in a series of investigations that within a given class or group of inhibitors the inhibiting effect depends on the molecular weight of a substance in a given class. Thus, Speller and Chappell [1], Sieverts and Lueg [2] and Rhodes and Kuhn [3] investigated the speed of solution of iron, aluminum and zinc in sulfuric and hydrochloric acids containing nitrogen compounds, starting from the simplest members and finishing with alkaloids, and found that the protective action of inhibitors increases with increasing molecular weight. In addition, they found a dependence between the protective action and the molecular structure and concentration of the inhibitor. They found that the inhibiting action is increased by introducing methyl, ethyl and amino groups into the molecules of acridine, pyridine, quinoline and their derivatives. For instance the introduction of one methyl group into the pyridine molecule increases the inhibiting effect by 25%. These observations, however, are not confirmed by other investigators. In fact, Rhodes and Kuhn themselves remark that the introduction of hydroxyl groups into organic nitrogen compounds – pyridine, quinoline and acridine – causes not an increase, but a decrease of protective action. Consequently not every group introduced into a molecule of a given inhibitor causes a rise in protective action.

The molecular structure of the inhibitor also has a considerable influence on the change of rate of solution of the metal. Thus, Mann, Lauer and Hultun [4] found, in a study of the action of aliphatic amines, that secondary amines protect iron against solution in acids better than primary amines, while tertiary amines are better protectors than secondary amines. The same authors found that iso compounds have a lower inhibiting effect than normal compounds.

We have systematically investigated the inhibiting effect of aliphatic and aromatic aldehydes on acidic corrosion with the objective of determining the effect of molecular weight and structure of the aldehydes on their protective action.

Experimental procedure. We used a gravimetric method for the most part, but a volumetric method in some cases. Portevin's method was also applied to the examination of the kinetics during the initial stage of dissolution of metal in acid. Chemically pure aldehydes were utilized as inhibitors. These were formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isobutyraldehyde and enanthaldehyde (aliphatics), and benzaldehyde, cuminaldehyde and tolualdehyde (aromatics). The test objects were sheets of boiler-plate (steel 20) with dimensions of 21 x 50 x 2.5. The corrosive medium was sulfuric acid (chemically pure) in various concentrations, in the amount of 70 ml per sheet. Small beakers containing the inhibitors were placed in a thermostat an hour before an experiment in order to establish the required temperature. All experiments were performed at 25° ± 0.1° for a period of 3 hours.

Prior to an experiment, the sheets were treated by our standard method, namely, they were polished to high gloss with the appropriate grades of emery cloth, washed with alcohol and ether, brought to constant weight in a desiccator, and weighed. Following an experiment, the layer of rust was removed with water and the sheet washed with alcohol and ether before reweighing. The loss in weight was calculated as grams per square meter per hour. The inhibiting effect was calculated from the formula:

$$\gamma = \frac{\rho_0}{\rho},$$

where γ is the inhibiting effect, ρ_0 is the velocity of solution of the metal in the uninhibited acid, ρ the velocity of solution in the inhibited acid.

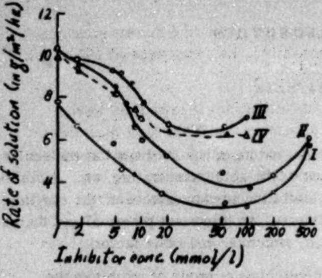

Figure 1. Dependence of rate of solution of steel in 5 N sulfuric acid on the nature and concentration of the inhibitors. I)formaldehyde; II) acetaldehyde; III) propionaldehyde; IV) butyraldehyde

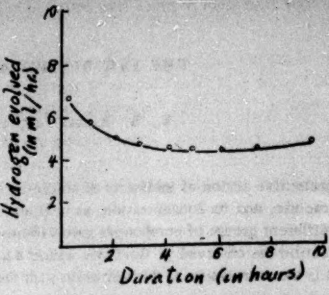

Figure 2. Rate of dissolution of steel in 5 N sulfuric acid in presence of butyraldehyde.

As mentioned above, in some cases, we also utilized a volumetric method. For this purpose we employed a cylindrical funnel fixed to a buret. Each experiment was repeated several times.

Aliphatic aldehydes. Formaldehyde and acetaldehyde were investigated in solutions containing 1 to 500 mmol/liter; propionic aldehyde and butyraldehyde in concentrations of 1 to 100 mmol/liter (due to their limited solubility). Results are presented in Table 1 and Figure 1.

TABLE 1

Inhibiting Action of Formaldehyde, Acetaldehyde, Propionaldehyde and Butyraldehyde on the Dissolution of Steel in 5 N Sulfuric Acid

Conc. of aldehydes (in mmol/l)	Speed of solution (in g/m²/hour)				Inhibiting effect			
	form-aldehyde	acet-aldehyde	propion-aldehyde	butyr-aldehyde	form-aldehyde I	acet-aldehyde II	propion-aldehyde III	butyr-aldehyde IV
0	12.24	12.24	12.24	12.24	1.00	1.00	1.00	1.00
1	7.92	10.38	10.00	10.38	1.54	1.2	1.22	1.18
2	6.94	9.81	9.65	9.15	1.76	1.25	1.27	1.34
4	5.96	8.41	9.29	8.0	2.05	1.46	1.32	1.49
6	4.92	7.88	9.01	7.90	2.49	1.55	1.36	1.55
8	4.56	6.91	8.47	7.49	2.68	1.77	1.45	1.67
10	3.87	6.12	7.79	7.13	3.17	2.00	1.57	1.72
20	3.47	5.30	6.83	6.72	3.53	2.31	1.79	1.82
50	3.10	4.45	6.66	6.48	3.95	2.75	1.48	1.89
100	2.84	3.58	7.10	6.34	4.41	3.42	1.72	1.93
200	3.44	4.48	–	–	3.55	2.73	–	–
500	5.75	5.85	–	–	2.12	2.01	–	–

We observe from Table 1 and Figure 1 that the velocity of solution of the metal (g/m²/hour) decreases with increasing concentration of formaldehyde, falls to a minimum at a concentration of 100 mmol/liter, and again starts to increase with further increase in concentration.

Concerning the inhibiting action of acetaldehyde, it might have been expected, as stated in the literature, that its protective action would surpass that of formaldehyde due to its higher molecular weight, but our data show that acetaldehyde is a weaker inhibitor than formaldehyde at all concentrations. It is interesting to note that the inhibiting action of acetaldehyde increases in the same way as that of formaldehyde but only up to a certain concentration. The maximum of protective action of acetaldehyde occurs at the same concentration as for formaldehyde.

Coming to the next aldehyde in order of molecular weight (propionaldehyde), we find that its protective action is weaker than that of formaldehyde or acetaldehyde. At all concentrations, with exception of 100 mmol/liter, the inhibiting action of propionaldehyde increases with increasing concentration.

Consequently, above certain concentration the inhibiting action of the aldehydes is extremely weak, and at still higher concentrations the aldehydes accelerate the corrosion. Similar observations were made for the first time in respect of formaldehyde by Balezin and Novikov [5]. We propose to call that concentration of inhibitor at which limiting protective action is attained the maximum effective concentration. As our experiments showed, the maximum effective concentration is not identical for all the aldehydes. It also follows from our data that the higher the molecular weight of the aldehydes, the lower their inhibiting effect, while the higher the aldehyde concentrations after attainment of the maximum effective concentration the weaker the inhibiting action of the aldehyde.

A volumetric method was utilized for studying the velocity of solution of the metal in the inhibiting acid. We studied the rate of evolution of hydrogen by determining the time required for 5 ml of hydrogen to be released from a buret filled with a solution of the inhibited acid. The observations showed that in the case of acetaldehyde-inhibited acid, at first hydrogen was evolved rather vigorously and then the rate fell off, only to increase again after a certain period. The same phenomenon was noted with butyraldehyde, as shown in Figure 2. In the case of acetaldehyde the change in rate of dissolution after the maximum effective concentration was higher than in the case of butyraldehyde. This phenomenon was at first puzzling. We carried out a series of supplementary experiments to clarify it, studying the kinetics of solution of the metal over a period of several days in propionaldehyde-inhibited 5 N sulfuric acid at a temperature of 20°. The results showed that the rate of solution of the metal increases with passage of time regardless of the presence of inhibitor in fairly high concentrations (Table 2).

TABLE 2

Rate of Dissolution of Steel in Propionaldehyde – Inhibited Acid (Inhibitor Conc. 50 mmol/l)

Duration of expt. (in hrs)	Loss of wt. (g/m²/hr)	Inhibiting effect
2	6.42	1.91
12	7.87	1.55
25.5	9.07	1.35
37.5	10.02	1.22
50.0	11.55	1.10

TABLE 3

Inhibiting Effect of Aldehydes (Volumetric Method of Investigation; Amount of Inhibitor 50 mmol/l)

Name of inhibitor	Mol.wt. of inhibitor	No. of ml H_2 released per hr	Inhibiting effect
Formaldehyde	30.02	0.66	13.96
Acetaldehyde	44.03	1.84	4.94
Propionaldehyde	58.05	3.42	2.68
Butyraldehyde	72.06	4.71	1.94
Isobutyraldehyde	72.06	3.26	2.8

The data of Table 2 show that the inhibiting effect of propionaldehyde gradually declines but not uniformly.

Investigation of the inhibiting effect of some aliphatic aldehydes by the volumetric method showed that their protective action falls off with rising molecular weight (Table 3).

These experiments show that the higher the molecular weight the lower the inhibiting effect of the aldehyde (Figure 3).

Effect of products of reduction of aldehydes on their protective action. As was shown, the protective action first increases with increasing concentration of aldehydes and subsequently begins to decrease. We have suggested that this is the consequence of reduction of the aldehydes under the action of the hydrogen evolved during dissolution of the metals in acid. Conversion of aldehydes into alcohols is a well-known reaction. The literature states that this reduction proceeds under the effect of certain catalysts and in certain conditions of the medium. For example, as far back as 1895, Kaufman [6] studied the reduction of benzaldehyde by atomic hydrogen, and Law [6] has studied the reduction of a series of aromatic aldehydes. Reduction of aldehydes to alcohols by hydrogen is also described in a number of patents.

We must, therefore, assume that also in our experiments reduction of aldehydes takes place. We therefore performed a number of experiments to determine the susceptibility of aldehydes to reduction, as a function of their molecular weight. The results are presented in Table 4.

TABLE 4

Susceptibility of Aldehydes to Reduction to Alcohols

Aldehyde	Amt. of hydrogen evolved (in ml)*	Vol. of hydrogen actually evolved (in ml)	Amount of hydrogen used in the reduction	
			(in ml)	(in %)
Formaldehyde	54.42	44.57	9.85	18.10
Acetaldehyde	49.20	44.66	4.54	9.25
Propionaldehyde	47.60	44.48	3.12	6.55
Butyraldehyde	46.20	44.25	1.94	4.26

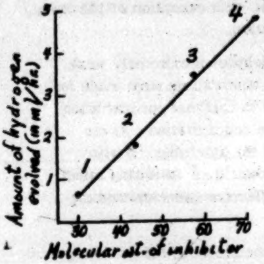

Figure 3. Dependence of rate of dissolution of steel in 5 N sulfuric acid on the molecular weight of the inhibitor. 1) formaldehyde; 2) acetaldehyde; 3) propionaldehyde; 4) butyraldehyde

The volumetric method brings out the point that with increasing concentration above the maximum inhibiting point, the velocity of dissolution increases, since the susceptibility of the aldehydes to reduction depends on their concentration in solutions. Our data for the susceptibility of aldehydes to reduction at various concentrations are presented in Table 5.

TABLE 5

Susceptibility of Aldehydes to Reduction at Various Concentrations

Conc. (in mmol/l)	Duration of expt. (hrs)	Total hydrogen formed (in ml)	Vol. of hydrogen actually evolved (in ml)	Amount of hydrogen			Inhibiting effect
				evolved per hr (in ml)	consumed in reduction		
					(in ml)	(in %)	
50	24.8	49.20	44.66	1.84	4.54	9.25	4.98
100	28.0	56.90	44.90	1.60	12.00	21.1	5.71
250	33.8	68.93	44.84	1.33	24.09	34.9	6.90
500	41.6	94.58	46.29	1.11	48.22	51.0	8.22

We see from the data of Table 5 that the volume of hydrogen collecting in the buret at certain concentrations is less than the volume of hydrogen formed in reaction between metal and acid. With increasing concentration, the difference between these volumes increases.

We see from the presented data that with rising aldehyde concentration the inhibiting effect is intensified, but side by side an opposing effect is developed, an effect which promotes solution. Above a certain concentration the protective action of the inhibitor begins to fall off because the solution-promoting effect then begins to predominate.

The reduced aldehyde promotes solution because, like any other oxidizing agent, it brings about removal of hydrogen from the surface of the metal and, consequently, makes room for release of fresh hydrogen ions, i.e. it accelerates the process of solution of the metal. Hence the higher the concentration of aldehyde, the greater its oxidizing effect. At certain concentrations of aldehydes, the latter begin to lose their protective action.

Protective action, molecular weight and molecular structure of the inhibitor. On the basis of the experimental results the inhibiting action of aldehydes may be expressed by the equation:

$$\gamma = 1 + \frac{K}{M},$$

where $\underline{M}$ is the molecular weight and $\underline{K}$ a constant.

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* The volumes of hydrogen are here and later converted to normal conditions.

Our results are entirely in conflict with established views on the relation between inhibiting effect and molecular weight. We have already noted that it is asserted in the publication of a series of investigators that the magnitude of the inhibiting effect increases with increasing molecular weight. Our experiments have shown that in respect to the aliphatic aldehydes the reverse relationship holds.

Other experiments were performed to clarify the relative inhibiting effects of iso and normal compounds. The substances used in these tests were butyraldehyde and isobutyraldehyde. On the basis of the literature it was to be expected that butyraldehyde would be a better inhibitor than isobutyraldehyde. In the case of amines, for instance, Mann, Lauer and Hultun found that iso compounds have a lower inhibiting power. We obtained contradictory results (Table 6).

TABLE 6

Inhibiting Effect of Butyraldehyde and Isobutyraldehyde

Conc. (mmol/l)	Speed of solution (g/m²/hr)		Inhibiting effect	
	butyraldehyde	isobutyraldehyde	butyraldehyde	isobutyraldehyde
1	10.38	10.01	1.28	1.11
2	9.15	10.00	1.34	1.22
4	8.22	9.07	1.49	1.35
6	7.90	8.66	1.55	1.41
8	7.49	8.50	1.67	1.44
10	7.13	8.14	1.72	1.50

TABLE 7

Inhibiting Effect of Acetaldehyde and Benzaldehyde

Conc. of aldehydes	Speed of solution (g/m²/hr)		Inhibiting effect	
	acetaldehyde	benzaldehyde	acetaldehyde	benzaldehyde
1	10.38	10.79	1.2	1.13
2	9.81	9.29	1.25	1.32
4	8.41	7.45	1.46	1.64
6	7.88	7.05	1.55	1.74
8	6.91	6.63	1.77	1.84
10	6.12	6.64	2.00	1.85

We see that butyraldehyde is a better inhibitor than isobutyraldehyde. We obtained different results in experiments using the volumetric method. Table 3 shows that the rate of evolution of hydrogen per hour is higher in presence of butyraldehyde than in presence of isobutyraldehyde The resultant calculations give a higher inhibiting effect with isobutyraldehyde than with butyraldehyde.

In our view, the divergence between the results of gravimetric and volumetric experiments can be interpreted as follows: it was previously shown that with increasing molecular weight, i.e., with lengthening of the carbon chain of the aldehydes, the inhibiting effect declines. Isobutyraldehyde has a shorter chain than normal butyraldehyde, and it is therefore natural to expect a higher inhibiting effect with the former. This is evidently associated with the fact that butyraldehyde is reduced by atomic hydrogen more readily than isobutyraldehyde.

Aromatic aldehydes. We have made a comparison of the inhibiting effects of aromatic and aliphatic aldehydes. Comparative data for acetaldehyde and benzaldehyde are given in Table 7.

The results indicate that the rate of solution of metal is slowed down more uniformly with acetaldehyde than with benzaldehyde. With benzaldehyde, the rate of solution falls sharply as the concentration changes from 1 to 4 mmol/l and then is inhibited at an approximately uniform rate.

Inhibiting action of emulsions of aldehydes. Taking advantage of the ability of enanthaldehyde and cuminaldehyde to dissolve readily in ethyl alcohol, we dissolved definite amounts of these aldehydes in 50 ml 95% ethyl alcohol and then diluted the solutions with water to form emulsions. These were examined as inhibitors of acidic corrosion (Table 8).

TABLE 8

Inhibiting Action of Emulsions of Enanthaldehyde and Cuminaldehyde

Conc. of aldehydes (mmol/l)	Rate of solution (g/m²/hr)		Inhibiting action	
	enanthaldehyde	cuminaldehyde	enanthaldehyde	cuminaldehyde
0.5	–	9.04	–	1.35
1	9.86	7.84	1.24	1.56
2	9.16	6.99	1.34	1.75
4	8.30	6.42	1.47	1.91
6	7.60	6.45	1.61	1.99
9	6.83	5.58	1.79	1.86
10	6.10	6.64	2.00	1.84

We see that the rate of solution of metals in presence of enanthaldehyde falls more uniformly than in presence of cuminaldehyde.

Cuminaldehyde has a higher molecular weight than enanthaldehyde and at concentrations of 10 mmol/l it possesses a lower inhibiting effect.

The results of investigation of aldehyde emulsions thus demonstrate that not only solutions of aldehydes, but also emulsions of aldehydes exert an inhibiting action, while with the latter a characteristic feature is that the inhibiting effect falls off with rising molecular weight.

SUMMARY

1. We have refuted in the case of aldehydes the widely held belief that the inhibiting effect is intensified with increasing molecular weight.

2. It is shown that aldehydes act on the dissolution of steel in two directly opposing directions —inhibition of dissolution and acceleration thereof. At a certain magnitude of concentration, acceleration of dissolution of metal in acid begins to predominate.

3. The inhibiting action of aldehydes increases with rise of concentration only up to a determined value of the concentration. The rate of reduction of aldehydes, and consequently the accelerating effect, increases with rising concentration of the aldehyde and decreases with increasing molecular weight.

4. Emulsions of aldehydes are also shown to act as inhibitors.

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AROMATIC DISULFIDES AND MERCAPTANS

1. 2-MERCAPTO-4-NITROBENZOIC ACID AND ITS TRANSFORMATIONS

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In recent years p-aminosalicylic acid and its derivatives have attracted the attention of investigators owing to the high antitubercular activity of the acid. For the same reason attention is merited by p-amino-o-mercaptobenzoic acid (p-aminothiosalicylic acid) particularly since its gold-sodium salt has also been utilized for some years in tuberculosis therapy [1].

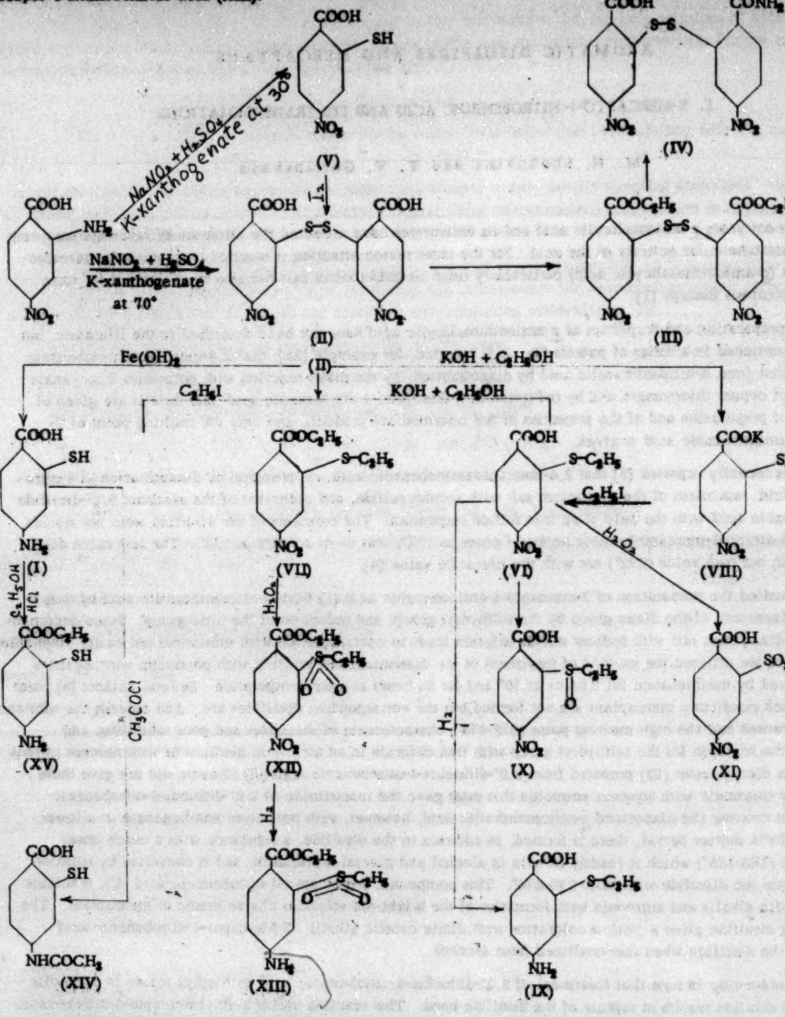
The preparation and properties of p-aminothiosalicylic acid have not been described in the literature, but have been mentioned in a series of patents [2]. It is reported, for example [2b], that 2,4-mercaptoaminobenzoic acid is prepared from 4-nitroanthranilic acid by diazotization, by the diazo reaction with potassium thiocyanate in presence of copper thiocyanate and by reduction of 2-thiocyano-4-nitrobenzoic acid. No details are given of the method of preparation and of the properties of the intermediate products, and only the melting point of 2-mercapto-4-aminobenzoic acid is given.

It was recently reported [3] that 2,4-mercaptoaminobenzoic acid was prepared by diazotization of 4-nitroanthranilic acid, treatment of the diazonium salt with sodium sulfide, and reduction of the resultant 2,2'-disulfide of 4-nitrobenzoic acid with the help of an iron sulfide suspension. The constants of the disulfide were not stated; the m.p. of 4-amino-2-mercaptobenzoic acid was given as 197°; that of its acetate as 137°. The last value does not agree with our own value (292°) nor with the literature value [4].

We studied the preparation of 2-mercapto-4-aminobenzoic acid (I) from 4-nitroanthranilic acid by diazotization, replacement of the diazo group by the sulfhydryl group, and reduction of the nitro group. Since decomposition of the diazonium salt with sodium sulfide solution leads to contamination with substances not easily amenable to purification, we utilized the method of treatment of the diazonium salt solution with potassium xanthogenate at 50°, followed by maintenance for 3 hours at 70° and for 24 hours at room temperature. Several authors [5] point out that in such conditions mercaptans are not formed, but the corresponding disulfides are. And indeed, the substance which we obtained had the high melting point (272-274°) characteristic of disulfides and poor solubility, and did not give the reaction for the sulfhydryl group with iron chloride in an alcoholic medium or with nascent nitrous acid [6]. The diethyl ester (III) prepared from 2,2'-dithiobis-4-nitrobenzoic acid (II) likewise did not give these reactions. By treatment with aqueous ammonia this ester gave the monoamide of 2,2'-dithiodi-4-nitrobenzoic acid (IV). On treating the diazotized p-nitroanthranilic acid, however, with potassium xanthogenate at a lower temperature for a shorter period, there is formed, in addition to the disulfide, a substance with a much lower melting point (183-185°) which is readily soluble in alcohol and glacial acetic acid, and is converted by titration with iodine into the disulfide with m.p. 270-274°. This compound, 2-mercapto-4-nitrobenzoic acid (V), is soluble in dilute caustic alkalis and ammonia with formation of the bright-red solutions characteristic of mercaptans. The corresponding disulfide gives a yellow coloration with dilute caustic alkalis. 2-Mercapto-4-nitrobenzoic acid changes into the disulfide when recrystallized from alcohol.

It is interesting to note that treatment of 2,2'-dithiobis-4-nitrobenzoic acid with ethyl iodide in alcoholic caustic alkali solution results in rupture of the disulfide bond. This reaction yields 2-ethylmercapto-4-nitrobenzoic acid (VI) and a small quantity of its ethyl ester (VII). The same acid is obtained by acting on the disulfide with diethyl sulfate and alkali. Rupture of the disulfide bond also takes place under the action of alcoholic potassium hydroxide when the dark-red crystalline potassium mercaptide of 2-mercapto-4-nitrobenzoic acid (VIII) is formed, heating of which with ethyl iodide leads to the same 2-ethylmercapto-4-nitrobenzoic acid. The latter is converted into 2-ethylmercapto-4-aminobenzoic acid (IX) by reduction with hydrogen in presence of skeletal nickel catalyst, while the corresponding sulfoxide (X) and sulfone [7] (XI) are obtained by oxidation with the calculated amount of 30% hydrogen peroxide.

Similarly the ethyl ester of 2-ethylmercapto-4-nitrobenzoic acid was converted by 30% hydrogen peroxide into the sulfone (XII), hydrogenation of which in presence of skeletal nickel catalyst gave the ethyl ester of 2-ethylmercapto-4-aminobenzoic acid (XIII).


COOH
SH
NO₂
(V)
NaNO₂ + H₂SO₄
K-xanthogenate at 30°
I₂
COOH
CONH₂
S–S
(IV)
NH₂
NaNO₂ + H₂SO₄
K-xanthogenate
at 70°
(II)
COOC₂H₅
(III)
Fe(OH)₂
(II)
KOH + C₂H₅OH
C₂H₅I
KOH + C₂H₅OH
S–C₂H₅
(I)
(VII)
(VI)
COOK
SK
(VIII)
C₂H₅I
H₂O₂
C₂H₅OH
HCl
CH₃COCl
H₂O₂
H₂
SO₂C₂H₅
(XV)
(XII)
(X)
(XI)
NHCOCH₃
(XIV)
(XIII)
(IX)

A more convenient method for preparation of 2-mercapto-4-aminobenzoic acid (I) proved to be the reduction of the 2,2'-disulfide of 4-nitrobenzoic acid with ferrous hydroxide [8]. The acid obtained in 65% of the theoretical yield gives a definite reaction for the presence of a sulfhydryl group. It melts at 197-198° and forms salts both with bases and with acids, but the latter are very easily hydrolyzed so that the acid can be recovered from an ammoniacal solution of its salt by acidification with hydrochloric acid. Its hydrochloride cannot be recrystallized even from absolute alcohol.

2-Mercapto-4-aminobenzoic acid reacts with bases, to form salts, both at the carboxyl and at the sulfhydryl group. It titrates with two equivalents of alkali.

Reaction of 2-mercapto-4-aminobenzoic acid with an equimolecular amount of acetyl chloride in presence of pyridine gives 4-acetamino-2-mercaptobenzoic acid (XIV). The ethyl ester of 2-mercapto-4-aminobenzoic acid (XV) is formed by esterification with ethyl alcohol in presence of hydrogen chloride.

The reactions carried out in this investigation are summarized in the above scheme.

EXPERIMENTAL

1. 2,2'-Dithiodi-4-nitrobenzoic acid (II). To a mixture of 12 g 4-nitroanthranilic acid and 30 ml water is added dropwise with cooling and stirring 14.5 ml concentrated sulfuric acid. The mixture is then cooled to +2° and dropwise addition is made of a solution of 7.8 g sodium nitrite in 11 ml water. After keeping for an hour, the reaction mixture is added with energetic stirring to a solution of 12 g potassium xanthogenate and 45 g sodium carbonate in 400 ml water heated to 50°. The temperature of the cherry-red solution is then raised to 70° and held there for 3 hours and then at room temperature for 24 hours. The yellow crystalline precipitate is filtered off, dissolved in a little water, filtered, and again precipitated, as a light-yellow mass, by means of concentrated hydrochloric acid. The precipitate is filtered, washed with water and dried to give 5.8 g of material melting with decomp. at 268-275°. After recrystallization, first from glacial acetic acid and then from acetone, 2,2'-dithiodi-4-nitrobenzoic acid is obtained in the form of light-yellow, fine crystals with m.p. 272-274°. The acid is readily soluble in acetone, soluble in hot alcohol, glacial acetic acid and dioxan, insoluble in water, ether, petroleum ether, benzene, chloroform and carbon tetrachloride; it dissolves very readily in bicarbonate solution and dilute caustic alkalis to form light-yellow solutions. It dissolves in strong caustic alkalis with a dark-cherry coloration. Its ammonium, sodium and potassium salts crystallize in large, light-yellow needles which are soluble in water. It does not give a positive reaction for the sulfhydryl group either with iron chloride in alcohol or with sodium nitrite in glacial acetic acid; it does not decolorize 0.1 N iodine solution.

3.300 mg substance: 5.125 mg CO_2; 0.721 mg H_2O. 6.100 mg substance: 0.387 ml N_2 (23.5°, 738.0 mm). 5.351 mg substance: 6.070 mg $BaSO_4$. Found %: C 42.36; H 2.44; N 7.09; S 15.57. $C_{14}H_8O_8N_2S_2$. Calculated %: C 42.4; H 2.03; N 7.07; S 16.18.

After the precipitate had been separated from the reaction mixture, the filtrate was treated with concentrated hydrochloric acid to bring down an additional 3.9 g of 2,2'-dithiodi-4-nitrobenzoic acid with m.p. 230-235° which after two recrystallizations from glacial acetic acid gave the pure acid with m.p. 272-274°.

2. Diethyl ester of 2,2'-dithiodi-4-nitrobenzoic acid (III). A mixture of 2.4 g 2,2'-dithiodi-4-nitrobenzoic acid, 1 ml concentrated sulfuric acid and 24 ml absolute ethyl alcohol is heated at the boil for 20 hours. The crystalline precipitate is filtered, well washed with water, dried and recrystallized from glacial acetic acid. Yield 1.2 g of light-yellow needles with m.p. 177°. After a second recrystallization from glacial acetic acid the diethyl ester of 2,2'-dithiodi-4-nitrobenzoic acid has m.p. 178-179°. It does not give the sulfhydryl reaction with iron chloride and sodium nitrite, and it does not decolorize iodine solution. It is readily soluble in acetone and dioxan, soluble in hot glacial acetic acid and hot alcohol, insoluble in benzene, chloroform, water and bicarbonate solution.

6.485 mg substance: 0.361 ml N_2 (24°, 726 mm). Found %: N 6.13. $C_{18}H_{16}O_8N_2S_2$. Calculated %: N 6.19.

3. 2,2'-Dithiodi-4-nitrobenzoic acid monoamide (IV). 2 g of diethyl ester of 2,2'-dithiodi-4-nitrobenzoic acid is heated with 20 ml 25% aqueous ammonia in a sealed tube at 100° for 20 hours. The solution is filtered from the small precipitate and treated with dilute hydrochloric acid to bring down 1.25 g of dark-yellow precipitate. After four recrystallizations from glacial acetic acid, the monoamide of 2,2'-dithiodi-4-nitrobenzoic acid is obtained as a light-yellow substance with m.p. 278-280°, soluble in bicarbonate, alcohol, acetone and dilute acetic acid, insoluble in water and ether.

3.605 mg substance: 0.339 ml N_2 (19.5°, 736 mm). Found %: N 10.63. 4.837 mg substance: 3.74 ml 0.01 N H_2SO_4. Found %: N 10.82. $C_{14}H_9O_7N_3S_2$. Calculated %: N 10.63.

4. 2-Mercapto-4-aminobenzoic acid (I). 12 g anhydrous iron chloride is dissolved with heating in 100 ml water and ferrous hydroxide is precipitated with 25% aqueous ammonia solution. Gradual addition is then made of a hot solution of 2.2 g 2,2'-dithiodi-4-nitrobenzoic acid in 50 ml 25% aqueous ammonia. The dark-green precipitate

of ferric hydroxide. The mixture is kept for 15 minutes on the boiling water bath; it is then filtered and the precipitate thoroughly washed with hot water. The filtrate is evaporated to half of its original volume, cooled, and treated with glacial acetic acid to bring down a cream-colored precipitate of 2-mercapto-4-aminobenzoic acid. The precipitate is filtered, washed with water and dried. Yield 1.2 g. M.p., after two recrystallizations from glacial acetic acid, 197.5-198°. Readily soluble in bicarbonate and dilute caustic alkalis; soluble in acetone, dioxan, hot dilute alcohol and hot dilute acetic acid; insoluble in benzene, chloroform and cold water. The acid gives the sulfhydryl reaction with iron chloride in alcohol and with sodium nitrite in glacial acetic acid; it at once decolorizes 0.1 N iodine solution.

3.872 mg substance: 7.091 mg CO_2; 1.443 mg H_2O. 6.425 mg substance: 0.480 ml N_2 (24.5°, 737 mm). 4.862 mg substance: 6.553 mg $BaSO_4$. Found %: C 49.95; H 4.17; N 8.30; S 18.50. $C_7H_7O_2NS$. Calculated %: C 49.67; H 4.17; N 8.28; S 18.9. 0.1115 g substance: 13.32 ml 0.1 N NaOH. Found equivalent 83.7. Calculated equivalent 84.56.

2-Mercapto-4-aminobenzoic acid gives water-soluble ammonium, sodium and potassium salts; with silver, mercury and lead cations it forms water-insoluble precipitates. On passing an excess of dry hydrogen chloride into an alcoholic solution of 2-mercapto-4-aminobenzoic acid, there is formed a white precipitate of the hydrochloride, readily soluble in alcohol and water, insoluble in concentrated hydrochloric acid; m.p. 216-220°. It could not be recrystallized because it decomposes in water or alcohol or even in absolute alcohol with separation of the original 2-mercapto-4-aminobenzoic acid.

The picrate is prepared by mixing an alcoholic solution of 2-mercapto-4-aminobenzoic acid with a hot alcoholic solution of the calculated amount of picric acid. The picrate does not come down on cooling; it is therefore separated with a large quantity of ether. It is obtained as fine, light-yellow crystals with m.p. 216°.

5. Ethyl ester of 2-mercapto-4-aminobenzoic acid (XV). 1 g 2-mercapto-4-aminobenzoic acid is dissolved in 50 ml absolute alcohol and dry hydrogen chloride is passed through until the weight increase is 0.23 g (1.1 mole). The solution is refluxed for 6 hours, evaporated to dryness in vacuum and treated with saturated bicarbonate solution. The precipitate is filtered and washed with water. Yield 0.52 g. After two recrystallizations from alcohol (1 : 1) the m.p. of the ethyl ester of 2-mercapto-4-aminobenzoic acid was 198°. Soluble in acetone, glacial acetic acid, and hot dilute alcohol; insoluble in benzene, petroleum ether, water and bicarbonate solution. Gives a positive sulfhydryl reaction with iron chloride and sodium nitrite.

6.790 mg substance: 0.428 ml N_2 (24°, 726 mm). Found %: N 6.92. $C_9H_{11}O_2NS$. Calculated %: N 7.10.

6. 2-Mercapto-4-acetaminobenzoic acid (XIV). 1 g 2-mercapto-4-aminobenzoic acid in 4 ml pyridine and 0.5 ml acetyl chloride are heated at the boil for two hours, after which the pyridine is distilled off and the residue treated with saturated sodium bicarbonate solution. The solution is filtered and treated with concentrated hydrochloric acid to precipitate 0.7 g 2-mercapto-4-acetaminobenzoic acid, a dark-yellow substance with m.p. 280-283°. After two recrystallizations from glacial acetic acid and one from alcohol the m.p. was 298-299°. It gives the sulfhydryl reaction with iron chloride. Soluble in dilute caustic alkalis, in alcohol, acetone and glacial acetic acid; insoluble in water, ether and benzene.

3.936 mg substance: 7.310 mg CO_2; 1.516 mg H_2O. 6.455 mg substance: 2.94 ml 0.01 N H_2SO_4. Found %: C 50.65; H 4.30; N 6.40. $C_9H_9O_3NS$. Calculated %: C 51.14; H 4.29; N 6.63.

7. 2-Ethylmercapto-4-nitrobenzoic acid (VI). To a cherry-red solution of 5 g 2,2'-dithiodi-4-nitrobenzoic acid in 6 ml 20% sodium hydroxide solution is added dropwise with energetic stirring 2 ml diethyl sulfate. At first the solution does not change color, but a precipitate gradually comes down and the solution acquires a light color. After heating for 5 hours on the boiling water bath, the mixture is cooled and treated with 10% sodium hydroxide solution. A small amount of insoluble material is separated by filtration and from the filtrate with the help of concentrated hydrochloric acid is precipitated a yellow substance which is filtered at the pump, well washed with water and dried. Yield 2.5 g 2-ethylmercapto-4-nitrobenzoic acid with m.p. 202-204°. After two recrystallizations from ethyl alcohol, the m.p. rose to 210-212°. The acid is soluble in acetone, hot alcohol, glacial acetic acid and dioxan; insoluble in water, chloroform and benzene.

3.492 mg substance: 6.117 mg CO_2; 1.304 mg H_2O. 5.585 mg substance: 0.315 ml N_2 (24°, 736 mm). 5.316 mg substance: 5.527 mg $BaSO_4$. Found %: C 47.77; H 4.17; N 6.28; S 14.27. $C_9H_9O_4NS$. Calculated %: C 47.54; H 3.99; N 6.17; S 14.12.

The same substance may be prepared from 2,2'-dithiodi-4-nitrobenzoic acid and ethyl iodide in alcohol alkali solution. To a solution of 5 g 2,2'-dithiodi-4-nitrobenzoic acid in 120 ml alcohol is added with stirring a solution of 2.8 g potassium hydroxide in 20 ml alcohol, then 4 g ethyl iodide, and the mixture boiled with good stirring for 9 hours. After cooling, 0.9 g of the original disulfide is recovered and the solution is evaporated to dryness and treated with bicarbonate solution. The bicarbonate-insoluble ethyl ester of 2-ethylmercapto-4-nitrobenzoic acid is separated, well washed with water and dried. Yield 0.6 g. After two recrystallizations from glacial acetic acid the m.p. is 80-81°. It does not give the sulfhydryl reaction with iron chloride. Readily soluble in alcohol, acetone, acetic acid; insoluble in water and bicarbonate.

6.200 mg substance: 0.308 ml N_2 (24.5°, 744 mm). Found %: N 5.58. $C_{11}H_{13}O_4NS$. Calculated %: N 5.49.

The remaining bicarbonate solution is acidified with hydrochloric acid to give a yellow precipitate which is filtered, well washed with water and dried. Yield of 2-ethylmercapto-4-nitrobenzoic acid 2.7 g. M.p. (from alcohol) 210-211°.

8. Reaction of 2,2'-dithiodi-4-nitrobenzoic acid with alcoholic potassium hydroxide. To a hot solution of 1.5 g 2,2'-dithiodi-4-nitrobenzoic acid in 100 ml alcohol is added a hot alcoholic solution of 2.1 g potassium hydroxide. The solution slowly reddens and on further boiling a dark-red, crystalline precipitate comes down. After heating for an hour, the precipitate is filtered, washed thoroughly with alcohol and ether. Yield 1.6 g of the potassium salt of 2-potassio-mercapto-4-nitrobenzoic acid. The mercaptide is highly soluble in water, sparingly soluble in alcohol, insoluble in ether. It could not be recrystallized. It crystallizes with one molecule of water which is lost in a vacuum desiccator at 100°.

0.2303 g substance: 0.0138 g H_2O. 3.121 mg substance: 3.240 mg CO_2; 0.548 mg H_2O. 7.900 mg substance: 0.340 ml N_2 (18.5°, 730 mm). Found %: C 28.31; H 1.36; N 4.85; H_2O 6.14. $C_7H_3O_4NSK_2 \cdot H_2O$. Calculated %: C 28.63; H 1.68; N 4.77; H_2O 5.97.

The potassium salt of 2-potassio-mercapto-4-nitrobenzoic acid is converted by boiling with ethyl iodide into 2-ethylmercaptobenzoic acid. Boiling is carried out for 30 minutes with alcohol and ethyl iodide, the insoluble residue is filtered off, and the filtrate evaporated to dryness in vacuum. The yellow residue, m.p. 220-230°, is recrystallized from glacial acetic acid and then has m.p. 208-210°. It does not depress the melting point of 2-ethylmercapto-4-nitrobenzoic acid.

9. 2-Ethylmercapto-4-aminobenzoic acid (IX). 0.8 g 2-ethylmercapto-4-nitrobenzoic acid in 50 ml alcohol is hydrogenated in presence of 2.0 g skeletal nickel catalyst at room temperature. The reaction is completed in 30 minutes. The solution is filtered, evaporated to dryness, and the residue treated with water. The white powder is separated. After two recrystallizations from glacial acetic acid, the melting point of the 2-ethylmercapto-4-aminobenzoic acid is 145.5-146°.

4.050 mg substance: 8.180 mg CO_2; 2.037 mg H_2O. 4.500 mg substance: 0.278 ml N_2 (19°, 732 mm). Found %: C 55.08; H 5.62; N 7.05. $C_9H_{11}O_2NS$. Calculated %: C 54.77; H 5.62; N 7.10.

10. 2-Ethylsulfoxide of 4-nitrobenzoic acid (X). To a solution of 1 g 2-ethylmercapto-4-nitrobenzoic acid in 50 ml glacial acetic acid is added 0.55 ml 27% hydrogen peroxide; long needles of the original acid separate out. After standing for 48 hours at room temperature the acicular crystals dissolve completely and the solution is evaporated to dryness in vacuum. Yield 1 g of the sulfoxide. After three recrystallizations alternately from 50% acetic acid and dilute alcohol, light-yellow crystals are obtained with m.p. 180-181°. 2-Ethylsulfoxido-4-nitrobenzoic acid dissolves readily in alcohol, acetone, glacial acetic acid and dioxan; sparingly in hot water, and not at all in ether.

6.985 mg substance: 0.344 ml N_2 (23.5°, 733 mm). Found %: N 5.56. $C_9H_9O_5NS$. Calculated %: N 5.76.

11. 2-Ethylsulfonyl-4-nitrobenzoic acid (XI). To a solution of 1 g 4-nitro-2-ethylmercaptobenzoic acid in 50 ml glacial acetic acid is added 1.6 ml 27% hydrogen peroxide (2.5 mole). At the end of two days the separated crystals of the original acid disappear and the solution is evaporated to dryness in vacuum. The slightly cream-colored sulfone is twice recrystallized from water in presence of carbon and then from glacial acetic acid. M.p. 191-192°. Very soluble in alcohol and glacial acetic acid, soluble in hot water, insoluble in cold water and ether.

3.813 mg substance: 5.871 mg CO_2; 1.096 mg H_2O. 8.471 mg substance: 0.385 ml N_2 (18.5°, 746 mm). Found %: C 41.99; H 3.22; N 5.11. $C_9H_9O_6NS$. Calculated %: C 41.67; H 3.50; N 5.45.

12. Ethyl ester of 2-ethylsulfonyl-4-nitrobenzoic acid (XII). To a solution of 0.82 g ethyl ester of 2-ethylmercapto-4-nitrobenzoic acid in 15 ml glacial acetic acid is added 1.5 ml 27% hydrogen peroxide. At the end of two days, the transparent solution is evaporated to dryness in vacuum. The white residue is recrystallized alternately from dilute acetic acid and alcohol. M.p. 105-107°. Very soluble in alcohol, glacial acetic acid and acetone; insoluble in hot and cold water.

4.689 mg substance: 7.830 mg CO_2; 1.949 mg H_2O. 7.497 mg substance: 0.323 ml N_2 (19°, 726 mm).
Found %: C 45.54; H 4.65, N 4.81. $C_{11}H_{13}O_6NS$. Calculated %: C 45.98; H 4.59; N 4.86.

13. Ethyl ester of 2-ethylsulfonyl-4-aminobenzoic acid (XIII). 0.5 g ester of 2-ethylmercapto-4-nitrobenzoic acid in 20 ml alcohol is hydrogenated in presence of 1.0 g skeletal nickel catalyst at room temperature. The reaction is completed in one hour. The solution is filtered and evaporated to dryness and the residue recrystallized three times alternately from alcohol and glacial acetic acid. M.p. 164-165°. Fine white crystals, readily soluble in alcohol, glacial acetic acid and acetone; insoluble in water.

3.909 mg substance: 7.414 mg CO_2; 2.108 mg H_2O. 8.199 mg substance: 0.400 ml N_2 (21°, 729 mm).
Found %: C 51.73; H 6.03; N 5.44. $C_{11}H_{15}O_4NS$. Calculated %: C 51.34; H 5.87; N 5.44.

SUMMARY

1. Diazotization of p-nitroanthranilic acid followed by treatment with potassium xanthogenate gave, depending on the temperature conditions, 2-mercapto-4-nitrobenzoic acid or its disulfide.

2. A study was made of the cleavage of 2,2'-dithio-bis-4-nitrobenzoic acid (disulfide) with alcoholic caustic alkali, its alkylation and esterification, and the action of ammonia on the ester.

3. 2-Ethylmercapto-4-nitrobenzoic acid and its ethyl ester were oxidized to the corresponding sulfoxide and sulfone.

4. 2-Ethylmercapto-4-aminobenzoic acid and the ethyl ester of 2-ethylsulfone-4-nitrobenzoic acid were prepared.

5. Reduction of 2,2'-dithio-bis-4-nitrobenzoic acid with ferrous hydroxide gave 2-mercapto-4-aminobenzoic acid, which was converted into the N-acetyl derivative and the ester.

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ARYLSULFIDYL QUINONEIMINES*

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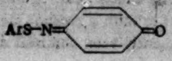
In previous papers we studied some substituted quinoneimines, namely: quinonebromimides [1,2], quinonediimides [3], and N-arylsulfonyl quinoneimines [4]. We showed that in the latter compounds the arylsulfonyl residue is split off in the form of an anion of an arylsulfonic acid under the action of alkaline solutions of phenols. In view of the importance of a study of the substitution reactions of quinoneimines, we decided also to investigate the compounds containing an arylsulfidyl radical.


(I).

Two representatives of this group of compounds – N-(4-chloro-2-nitrophenylsulfidyl)-1,4-benzoquinoneimine [5] and N-(4-tolylsulfidyl)-1,4-benzoquinoneimine [9] – are described in the literature; the authors in question, however, did not investigate their reactions with phenols. We have therefore repeated the synthesis of the first of these compounds and have studied its reaction with alkaline solutions of phenol and 1-naphthol. It transpired that the first compound only gives a blue coloration when heated in alcoholic alkali solution, i.e. it forms indophenols. Furthermore we synthesized N-(2,4-dinitrophenylsulfidyl)-1,4-benzoquinoneimine.

We synthesized arylsulfidyl quinoneimines in accordance with the scheme:

$$\mathrm{ArSSAr} \xrightarrow{Cl_2} \mathrm{ArSCl} \xrightarrow{\text{p-aminophenol}} \mathrm{ArSNHC_6H_4OH} \xrightarrow{O} \mathrm{ArSN{=}C_6H_4{=}O}.$$

Attempts to repeat the synthesis of N-(4-tolylsulfidyl)-1,4-benzoquinoneimine [9] were unsuccessful: reaction of tolylsulfide chloride with 1,4-aminophenol in anhydrous ether gave the corresponding 4-(tolylsulfidylamino)-phenol, but this compound was unexpectedly very unstable and broke down to ditolyldisulfide and other unidentified products during crystallization. In moist ether the reaction of tolylsulfidyl chloride with 1,4-aminophenol led directly to ditolyldisulfide, i.e. 1,4-aminophenol only had, so to speak, a reducing effect on tolylsulfide chloride. The formation of ditolyldisulfide most probably takes place via the decomposition of 4-(tolylsulfidylamino)-phenol according to the equation:

$$\mathrm{2CH_3C_6H_4SNH{-}C_6H_4OH \rightarrow CH_3C_6H_4SSC_6H_4CH_3 + HN{=}C_6H_4{=}O + H_2NC_6H_4OH.}$$

Formation of a quinoneimine is demonstrated by the development of a blue color on heating tolylsulfidylaminophenol with phenol in alkaline solution.

The (2,4-dinitrophenylsulfidyl)-1,4-benzoquinineimine, synthesized by us for the first time, like its known analog N-(4-chloro-2-nitrophenylsulfidyl)-1,4-benzoquinoneimine, had a yellow color and was fairly stable to heating; it melts without appreciable decomposition at a high temperature. Interest is attached to the action of phenol in alcoholic alkaline solution on these compounds. On heating there is developed an intense blue color or a correspondingly blended (yellow + blue) greenish-blue color due, it must be assumed, to formation of indophenol. The coloration was not observed in the cold in ammoniacal solution. With 1-naphthol in the same conditions a blue color is obtained; it must be pointed out that quinonechlorimide and quinonebromimide only give a violet coloration with 1-naphthol in an ammoniacal medium; in a medium of NaOH a blue color is developed. The violet stain formed with 1-naphthol when carrying out the quinonebromimide reaction becomes blue when moistened with 1 M caustic alkali.

We made a close examination of the action of N-(4-chloro-2-nitrophenylsulfidyl)-1,4-benzoquinoneimine on phenol in alcoholic alkaline solution; a product insoluble in the dilute alkali-alcohol solution was identified as

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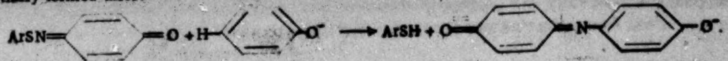
* The ArS radical is encountered in the literature under various names such as "arylthio" and "arylsulfid(yl)". Some substituted radicals, however (chlorides, amides, anilides, etc), are regarded as derivatives of an aryl sulfonic acid ArSOH; In conformity with this, the ArS radical is named "arylsulfen(yl)". But this name does not correspond to the composition of the radical, and we have adopted the consistent name "arylsulfidyl".

4,4'-dichloro-2,2'-dinitrodiphenyldisulfide. It appears probable that this compound is formed by oxidation of the initially formed thiol:



We know, of course, that thiophenols in alkaline solution are very rapidly oxidized to disulfides. This mechanism is supported by the fact that the isolated product at first has a low melting point and only acquires the melting point of the disulfide after keeping in the air.

Our observations have thus revealed the cleavage of the arylsulfidyl radical from arylsulfidyl quinoneimines; this fact is interesting both for characterization and identification of arylsulfidyl quininechlorimines and for our understanding of the relation between structure and properties of the radical and its ability to split off in the form of an ion from the substituted quinoneimine. We also synthesized 4-(4'-chloro-2'-nitrophenylsulfidyl)-aminoanisole and oxidized it with bichromate in glacial acetic acid. It was found that during oxidation with bichromate in glacial acetic acid, the latter combines to form a product identical with N-(4-chloro-2-nitrophenylsulfidyl)-1,4-benzoquinoneimine; evidence has consequently been obtained of cleavage of a methyl group during oxidation.

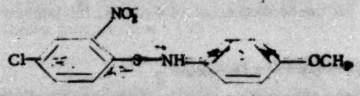
EXPERIMENTAL

The 4-chloro-2-nitrophenylsulfidyl chloride and 2,4-dinitrophenylsulfidyl chloride required for the experiments were prepared from the disulfides by the action of chlorine on a suspension in carbon tetrachloride [6].

N-(4-Chloro-2-nitrophenylsulfidyl)-1,4-benzoquinoneimine was synthesized by oxidation of 4-(4'-chloro-2'-nitrophenylsulfidylamino)-phenol [5]. The product after recrystallization from glacial acetic acid was in the form of small yellow needles melting at 194° in agreement with the literature.

No coloration is developed in the cold with phenol in alcoholic alkaline solution, but a deep blue color appears on heating. Simultaneously a yellow precipitate is formed whose amount increases when the solution is kept. The precipitate was filtered, washed and dried; m.p. 212°. The m.p. of 4,4'-dichloro-2,2'-dinitrodiphenyldisulfide is given as 212° [5].

4-(4'-Chloro-2'-nitrophenyl sulfidylamino)-anisole

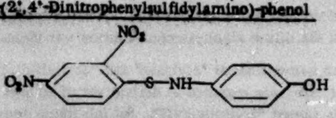


Into a solution of 10 g 4-chloro-2-nitrophenylsulfide-chloride in 150 ml absolute dry ether is introduced 10 g p-anisidine. The precipitate of p-anisidine hydrochloride is filtered off and the ethereal filtrate cooled to −15° when red crystals came out. After crystallization from glacial acetic acid the product melted at 127-128°. Sparingly soluble in benzene, insoluble in water, readily soluble in ether.

0.2156 g substance: 0.1580 g $BaSO_4$. Found %: S 10.07. $C_{13}H_{11}O_3N_2ClS$. Calculated %: S 10.32.

5 g of 4-(4'-chloro-2'-nitrophenylsulfidylamino)-anisole was dissolved in glacial acetic acid and addition was made of a concentrated solution of 5 g sodium bichromate in glacial acetic acid. The mixture was heated to the boil and allowed to stand. Next morning the yellow needlets were filtered and recrystallized from glacial acetic acid. M.p. 194°. A blue coloration appeared when heated with phenol in alkaline solution. It did not depress the melting point of the sulfidyl quinoneimine. It was thus established that oxidation of the corresponding methoxy derivative is accompanied by loss of the methyl group with formation of the sulfide-quinoneimine.

4-(2',4'-Dinitrophenylsulfidylamino)-phenol

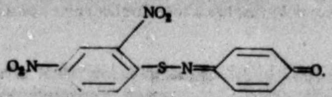


10 g 2,4-Dinitrophenylsulfidyl-chloride is dissolved in 150 ml ether, and 10 g p-aminophenol is added to the solution. The suspension of aminophenol in ether is boiled for an hour under a reflux condenser. The precipitate of

unreacted aminophenol and the aminophenol hydrochloride are filtered off and the ethereal solution cooled to −15°. The separated red crystals are filtered off and recrystallized from glacial acetic acid. Red leaflets, m.p. 155-156°, readily soluble in ether, sparingly in alcohol.

0.0980 g substance: 0.0788 g $BaSO_4$. Found %: S 11.0. $C_{12}H_9O_5N_3S$. Calculated %: S 10,4.

N-(2,4-Dinitrophenylsulfidyl)-1,4-benzoquinoneimine



Oxidation of the preceding compound was effected with bichromate in glacial acetic acid in similar conditions. Yellow needles were obtained which dissolved readily in ether and less easily in benzene and were insoluble in water. Two recrystallizations from glacial acetic acid gave yellow leaflets with m.p. 197-198°. A blue color appeared when heated with alkaline solutions of phenol and 1-naphthol. A yellow precipitate came down at the same time.

0.0874 g substance: 0.0710 g $BaSO_4$. Found %: S 10.2. $C_{12}H_7O_5N_3S$. Calculated %: S 10.5.

4-(4'-Tolylsulfidylamino)-phenol is similarly prepared from 4-tolylsulfidylchloride and 4-aminophenol in ethereal suspension. Red crystals with m.p. 68° come down from the ethereal solution. The literature gives m.p. 68° [9]. A blue color is formed when heated with phenol in alcoholic alkaline solution.

Hydrolysis occurs in aqueous alcohol. Two crystallizations from dilute alcohol give a colorless, odorless substance with m.p. 40°. It does not contain nitrogen and is insoluble in water and caustic alkali solutions. When the synthesis is performed in moist ether a colorless substance with m.p. 48° is obtained directly. A deep-violet color is developed on gentle heating in conc. sulfuric acid. Qualitative reactions identify it as ditolyldisulfide, m.p. 48° [7]. Oxidation of noncrystallizing tolylsulfidylaminophenol as well as of the colorless substance with m.p. 40° gives a colorless substance with m.p. 76°. The literature gives 78° as the melting point of ditolylsulfonedisulfide, $CH_3C_6H_4SO_2SC_6H_4CH_3$ [8]. It has therefore been demonstrated that the hydrolysis of tolylsulfidylaminophenol leads to ditolyldisulfide.

SUMMARY

1. N-(2,4-dinitrophenylsulfidyl)-1,4-benzoquinoneimine has been synthesized and its properties and reactions described.

2. Arylsulfidyldiquinoneimines give a blue coloration with phenol in alkaline solution; at the same time the arylsulfidyl residue is detached and the corresponding disulfide is formed.

3. In attempts to synthesize N-(4'-tolylsulfidyl)-1,4-benzoquinoneimine, it was established that tolylsulfidylaminophenol easily splits up with formation of ditolyldisulfide.

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* See Consultants Bureau English translation, p. 1917.

** See Consultants Bureau English translation, p. 1053.

*** See Consultants Bureau English translation, p. 1059.

[illegible] red crystals [illegible] filtered off [illegible] glacial acetic acid. [illegible] readily soluble in [illegible]

[illegible] g substance: [illegible] g $BaSO_4$. Found %: S [illegible]. [illegible] Calculated %: S [illegible].

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[illegible] with [illegible] alkaline solution. [illegible] a blue color appeared [illegible] A yellow precipitate [illegible] at the same time.

[illegible] g substance: [illegible] g $BaSO_4$. Found %: S [illegible]. Calculated %: S [illegible].

[illegible] was similarly prepared from [illegible] m.p. [illegible] A [illegible] alkaline solution.

[illegible] It does not contain nitrogen [illegible] When the product [illegible] [illegible] It has therefore been [illegible]

SUMMARY

1. [illegible] have been synthesized and their properties and reactions described.

2. [illegible] alkaline solution, at the same time [illegible]

3. [illegible]

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[7] [illegible] Clark, Handbook of Qualitative and Quantitative Analysis, [illegible]

[8] [illegible] Ber. [illegible]

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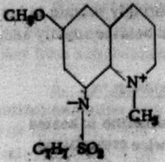
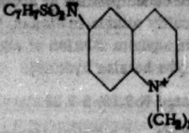
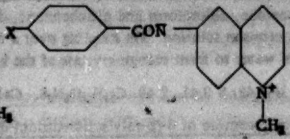
BIPOLAR IONS FORMED DURING CLEAVAGE OF A PROTON FROM THE NH GROUP. VI.

A. M. Simonov

It was shown in the preceding communications that quaternary ammonium salts containing a NH group attached to a 2,4-dinitrophenyl, picryl or arylsulfonyl radical can be converted, directly or via intermediate formation of a base, into characteristic bipolar ions (betainazeniates) [1]. The formation of a negative pole in the molecules of these compounds is caused by loss of a proton from the NH group. The influence of electron-accepting groups bound to the negatively charged N atom causes a fall in the electronic density at this atom. With the aim of further investigation of the conditions of formation and the properties of bipolar ions of this type, we have synthesized the compounds with structures (I) to (III) described in this communication:


(I)


(II)


a) X = H
b) X = NO_2
(III)

In the bipolar ion of (I) the onium N atom is in the o-position (position 8) to the azeniate atom of nitrogen; in this way the compound is distinguished from the previously described betaines of this type, belonging to the series of p- and m-derivatives. The bipolar ion of (II) is characterized by the presence of a high-molecular alkyl attached to the onium N atom. A feature of the structure of the bipolar ions of (III a) and (III b) is the presence of, respectively, a benzoyl and a p-nitrobenzoyl group attached to the azeniate nitrogen atom; notwithstanding the lower electron-accepting ability of these groups in comparison, say, with the p-tolylsulfonyl radical, these groups have been found experimentally to exhibit a sufficiently high mobility of the hydrogen at the NH group to form a betaine.

Compound (I) is easily prepared by dehydration of the base isolated from the corresponding quinoline salt by treatment with ammonia. A similar method is applied to the preparation of the bipolar ions (III a) and (III b); separation of the bases from the salts in this case, however, is only possible when using a considerable excess of caustic alkali. In contrast to these compounds, the bipolar ion of (II) is formed directly from the quinolinium salt by the action of ammonia or sodium hydroxide on its aqueous alcoholic solution; this effect is evidently due to the hydrophobic character of the alkyl group, since the preparation of the related methylbetaine is only possible through intermediate formation of the base.

The prepared bipolar ions possess the same properties as the previously investigated compounds of this type. They are deeply colored crystalline substances with rather high melting points, in most cases insoluble in nonpolar solvents. Only the bipolar ion of (I) is slightly soluble in dioxan; this enables the determination of its dipole moment. Compound (II) has an extremely low solubility in dioxan in spite of the presence of the high-molecular alkyl.

EXPERIMENTAL

1. 6-Methoxy-8-(p-tolylsulfonamido)-quinoline. To a solution of 5.25 g 6-methoxy-8-aminoquinoline in 25 ml pyridine bases (b.p. 120-140°) is added 5.7 g p-toluenesulfochloride in small portions, and the reaction mixture is heated at 80-90° for $\frac{1}{2}$ hour. On the following day the crystallized mass is transferred into 250 ml hot water and the residue is filtered off and washed with water. Yield 9.2 g. It is crystallized from alcohol, benzene, and again from alcohol. White crystals with m.p. 134-135°. The literature gives 131-132° [2].

Found %: S 9.56, 9.53. $C_{17}H_{16}O_3N_2S$. Calculated %: S 9.76.

The methyl-methosulfate of 6-methoxy-8-(p-tolylsulfonamido)-quinoline was prepared by heating 6-methoxy-8-(p-tolylsulfonamido)-quinoline with a small excess of freshly vacuum-distilled dimethylsulfate. The reaction was carried out for 3 hours at 105-110° (rise of temperature to 140° causes partial decomposition, and a vitreous melt is formed on cooling). Unreacted starting materials are washed out with boiling absolute benzene. The yield reaches 93%. White acicular crystals (from absolute alcohol), decomposing at 243-245°, very sparingly soluble in water, insoluble in acetone. When an aqueous suspension of the salt, made alkaline with potassium carbonate solution, is shaken with chloroform, the chloroform layer acquires a wine-red color due to the betaine formed.

2. Methylbetaine of 6-methoxy-8-(*p*-tolylsulfonamido)-quinoline (I)*. 4.0 g methyl-methosulfate of 6-methoxy-8-(*p*-tolylsulfonamido)-quinoline is placed in a conical flask and triturated with a rod with 20 ml 5% aqueous ammonia. A viscous red mass is formed. The aqueous solution is poured off and the viscous product is washed several times with dilute aqueous ammonia (kneading the mass with a rod). The product gradually crystallizes. It is dissolved with heating in a mixture of 25 ml alcohol and 10 ml water, filtered hot, and then 10 ml water is added. The resultant crystalline precipitate is filtered, washed with dilute alcohol and dried in a desiccator over sodium hydroxide. Yield 2.32 g. The product is twice recrystallised from 50% alcohol. The hot solution at first deposits reddish-orange acicular crystals; on cooling, orange clusters begin to form; they grow and gradually the whole precipitate becomes orange. After standing for several days in a desiccator over sodium hydroxide, the orange product (the base, the betaine hydrate) loses one molecule of water and is transformed into the betaine.

Found %: H_2O 5.04. $C_{18}H_{18}O_3N_2S \cdot H_2O$. Calculated %: H_2O 5.00.

The betaine forms red or crimson needles melting with decomposition at about 185°. It is insoluble in ether, soluble in acetone, chloroform and nitrobenzene, difficultly soluble in dioxan, very sparingly soluble in hot benzene to form a crimson solution. On standing over a dilute aqueous solution of alkali, the betaine rapidly adds on one molecule of water to form orange crystals of the base (the betaine hydrate).

Found %: N 8.42; S 9.41, 9.40. $C_{18}H_{18}O_3N_2S$. Calculated N 8.18; S 9.36.

3. Tetradecyl bromide of 6-(*p*-tolylsulfonamido)-quinoline. (6-*p*-Tolylsulfonamido)-quinoline is heated with a small excess of tetradecyl bromide at 160-170° for 4 hours. The soap-like product is twice crystallised from a small amount of alcohol and ether (yield 20%) and then from alcohol-acetone. White crystals, m.p. 202-204°.

Found %: Br 13.74. $C_{30}H_{43}O_2N_2SBr$. Calculated %: Br 13.83.

4. Tetradecylbetaine of 6-(*p*-tolylsulfonamido)-quinoline (II). 0.4 g of the tetradecyl bromide of 6-(*p*-tolylsulfonamido)-quinoline is dissolved in 12 ml 50% alcohol; gradual addition is then made to the hot solution of 2 ml 5% potassium hydroxide, followed by 3 ml water. The precipitate is washed with dilute alcohol and with water and dried in a desiccator over alkali. Two crystallizations from 90% alcohol give yellow crystals (clusters of fine needles) with a waxy softness. The substance does not lose weight when stood over phosphorus pentoxide or when heated in vacuum (30 mm) at 100°. The decomposition temperature of the betaine is about 214°. Trituration of the substance causes the color to change from yellow to red. It is soluble in nitrobenzene and chloroform, insoluble in carbon tetrachloride, almost insoluble in hot benzene; it dissolves to a slight extent in hot dioxan to form a red solution which decolorizes when cooled and separates the yellow betaine. The betaine does not combine with water when stood in a desiccator over a 2 N solution of alkali.

Found %: C 72.40; H 8.74; S 6.72. $C_{30}H_{42}O_2N_2S$. Calculated %: C 72.83; H 8.56; S 6.48.

5. Methyl-*p*-toluenesulfonate of 6-benzoylaminoquinoline. The starting 6-benzoylaminoquinoline was prepared by reacting 6-aminoquinoline with benzoyl chloride in acetone solution in presence of potassium carbonate, and it was purified by crystallization from dilute alcohol. M.p. 170.5-171° (the literature gives 169° [3]). The compound is converted into the quaternary salt by fusion with the methyl ester of *p*-toluenesulfonic acid at 180°.

Methyl-*p*-toluenesulfonate of 6-benzoylaminoquinoline forms slender white needles (from alcohol or water) with m.p. 263-265° (with decomposition), insoluble in benzene. Addition of 25% ammonia to the aqueous solution of the compound leads to a light-yellow coloration; the cooled solution deposits the original salt. Addition of sodium hydroxide to the solution yields a base which comes down as yellow rectangular platelets. When an aqueous solution of the salt made alkaline with sodium hydroxide is shaken with chloroform, the chloroform layer acquires a reddish-brown color.

Found %: S 7.32, 7.40. $C_{24}H_{22}O_4N_2S$. Calculated %: S 7.38.

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* The names given to the betaines described in this and previous papers are built upon the principle that each betaine is considered as an alkyl-substituted (with an onium N atom) betainic form of the corresponding amino acid; this nomenclatural principle enables clear recognition of the genetic relation between a betaine and the starting compounds (compare names of compounds 7, 8 and 9). Compounds of this type could also be named, in principal, with reference to the onium function of the molecule, considering the betaine as an inner salt of its corresponding onium base. For example, compound (I) may also be called the betaine of 6-methoxy-8-*p*-toluenesulfamino-1-methylquinolinium.

6. Methylbetaine of 6-benzoylaminoquinoline [betaine of 6-benzoylamino-1-methylquinolinium] (IIIa). 1 g of methyl-p-toluenesulfonate of 6-benzoylaminoquinoline is dissolved in 60 ml water. To the solution (cooled to 65°) is added dropwise 0.8 ml 10% sodium hydroxide; the solution turns yellow and becomes turbid on further cooling. An additional 9.5 ml 10% sodium hydroxide is gradually added. The resultant crystalline precipitate is filtered after standing for a short period, washed with dilute ammonia solution and then repeatedly with water, and dried in a desiccator over sodium hydroxide. Later the substance is washed with acetone until the filtrate, brown at first, is weakly colored. The yellow crystalline product obtained in a yield of 0.23 g (38%) forms rectangular platelets and is a base (hydrate of the betaine). It is insoluble in dioxan and benzene, soluble in nitrobenzene, pyridine and alcohol. It is unstable in solution. It loses water when stood over P_2O_5 in a vacuum desiccator and is converted into the betaine which forms brown-orange crystals, insoluble in dioxan and benzene. It darkens when heated in a capillary, turns black at about 170°, and gradually begins to melt above 205°.

Found %: N 10.65. $C_{17}H_{14}ON_2$. Calculated %: N 10.68.

When placed in a desiccator over 2 N alkali, the betaine turns yellow and changes into the base. When treated with an alcoholic solution of p-toluenesulfonic acid, the betaine dissolves and then forms a crystalline precipitate which is purified by recrystallization from methyl alcohol. The product is identical with the original methyl-p-toluenesulfonate of 6-benzoylaminoquinoline (m.p. 263-265°; no depression in mixed melting test).

7. 6-(4'-Nitrobenzoylamino)-quinoline. The compound is prepared by acylation of 6-aminoquinoline with p-nitrobenzoyl chloride in presence of sodium bicarbonate [4]. It forms yellow-white crystals after two crystallizations from nitrobenzene. M.p. 256.5-258° (the literature gives 248-250° [4].

8. Methyltoluenesulfonate of 6-(4'-nitrobenzoylamino)-quinoline. Prepared by fusing 6-(4'-nitrobenzoylamino)-quinoline with methyl p-toluenesulfonate at 125-135°. Slender, long, white needles (from dilute alcohol) with m.p. 301.5-303°. Addition of caustic alkali to the aqueous solution of the compound causes deposition of yellow crystals of the base; the base is not precipitated by addition of ammonia or sodium carbonate. When an alkalized solution of the salt is shaken with chloroform, the latter is colored a weak brownish-orange.

Found %: S 6.65, 6.63. $C_{24}H_{21}O_6N_3S$. Calculated %: S 6.69.

9. Methylbetaine of 6-(4' nitrobenzoylamino)-quinoline (IIIb). 1.0 g quaternary salt is dissolved in 60 mg 50% alcohol. To the solution at 70° is slowly added 4 ml 2 N potassium hydroxide; the solution turns orange. On cooling to 40°, a yellow crystalline precipitate begins to come down. A further 2 ml alkali solution is added to the cooled solution. After an hour the precipitate is filtered, washed with dilute alcohol and water and dried in a desiccator over alkali.

The brownish-yellow crystals consist of the base (the betaine hydrate). Yield 0.54 g (79%). The compound is soluble in hot dilute alcohol; it could not be recrystallized, however, due to decomposition when heated. The base loses one molecule of water in vacuum over phosphorus pentoxide and is converted into the betaine.

Found %: H_2O 5.54. $C_{17}H_{13}O_3N_3 \cdot H_2O$. Calculated %: H_2O 5.54.

The betaine forms lustrous red-brown crystals, insoluble in ether and benzene, very sparingly soluble in chloroform. It is slightly soluble in hot pyridine; brief heating causes partial decomposition of the betaine. The crystals blacken when heated in a capillary at a little above 200°; further rise of temperature to 290° does not cause melting. The betaine adds on one molecule of water when stood in a desiccator over dilute caustic alkali.

Found %: N 13.79, 13.93. $C_{17}H_{13}O_3N_3$. Calculated %: N 13.67.

SUMMARY

The preparation and properties of some new bipolar ions of the betaine-azeniate series are described.

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THIAZOLIDINE-4-CARBOXYLIC ACID AND ITS DERIVATIVES

III. CONDENSATION OF THIAZOLIDINE-4-CARBOXYLIC ACID AND ITS DERIVATIVES WITH 4-ETHOXYMETHYLENE-2-PHENYL-5(4)-OXAZOLONE

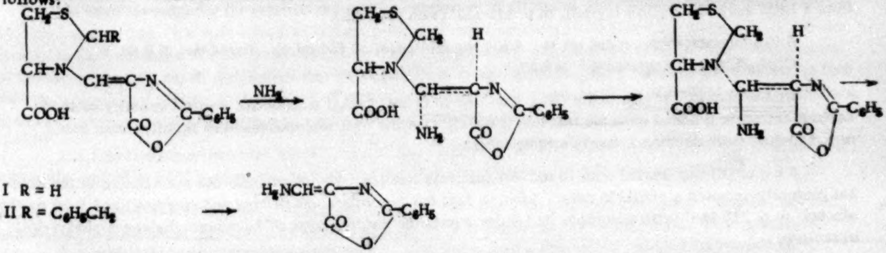
I. T. Strukov

4-Ethoxymethylene-2-phenyl-5(4)-oxazolone is exceptionally reactive. It enters very readily into reaction with ammonia and primary amines to form 4-aminomethylene-2-phenyl-5(4)-oxazolone or the corresponding 4-alkylaminomethylene-2-phenyl-5(4)-oxazolone [1].

In a study of the chemical properties of 4-aminomethylene-2-phenyl-5(4)-oxazolone it was established that the amino group can be replaced. Thus, on heating this compound with aniline, 4-anilinomethylene-2-phenyl-5(4)-oxazolone was obtained; this had previously been prepared by reacting 4-ethoxymethylene-2-phenyl-5(4)-oxazolone with aniline [1]. Livermore [2] treated dl-benzylpenicilloic acid with sodium hydroxide solution and obtained the crystalline sodium salt of 4-hydroxymethylene-2-benzyl-5(4)-oxazolone. Consequently the amino group in 4-aminomethylene-2-aryl-5(4)-oxazolones is amenable to exchange reactions.

4-Aminomethylene-2-phenyl-5(4)-oxazolone has a good deal in common with acid amides. In fact, 4-hydroxymethylene-2-phenyl-5(4)-oxazolone can be regarded as an acid (the compound titrates with sodium hydroxide): 4-methoxymethylene-2-phenyl-5(4)-oxazolone is reminiscent of the ester of this acid since it is readily saponified by acids and alkalis, while with ammonia it gives 4-aminomethylene derivatives [1]. However, in contrast to acid amides, 4-aminomethylene-2-phenyl-5(4)-oxazolone and its derivatives much more easily exchange their amino group for hydroxyl or another amino group.

It was interesting to determine whether 4-ethoxymethylene-2-phenyl-5(4)-oxazolone is capable of reacting with the imino group of thiazolidine-4-carboxylic acid [3]. Thiazolidine-4-carboxylic acid readily enters into reaction with it in a pyridine medium to form N-(2'-phenyl-5(4)'-oxazolonemethylene-4')-thiazolidine-4-carboxylic acid (I). This compound gives a well-characterized pyridinium salt. On treatment with 4% aqueous ammonia solution, compound (I) is quantitatively decomposed with formation of 4-aminomethylene-2-phenyl-5(4)-oxazolone. It is quite possible that temporary addition of ammonia takes place at the ethylene-imine bond, but this intermediate breaks down and 4-aminomethylene-2-phenyl-5(4)-oxazolone is precipitated. The reaction may be represented as follows:



I R = H
II R = $C_6H_5CH_2$

The reaction proceeds in the same way when 2-benzylthiazolidine-4-carboxylic acid is condensed with 4-ethoxymethylene-2-phenyl-5(4)-oxazolone and there is formed 2-benzyl-N-(2'-phenyl-5(4)'-oxazolonemethylene-4')-thiazolidine-4-carboxylic acid (II). The ammonium salt of this acid is poorly soluble in water, so that the reaction proceeds very slowly when the acid is treated with 25% aqueous ammonia solution; however, this reaction also yields 4-aminomethylene-2-phenyl-5(4)-oxazolone.

In their properties, compounds (I) and (II) are reminiscent of N-acylthiazolidine-4-carboxylic acid: they are likewise not susceptible to oxidation by iodine solution, a fact which distinguishes them from thiazolidine-4-carboxylic acid. Indeed, 4-hydroxymethylene-2-phenyl-5(4)-oxazolone possesses strongly marked acidic properties and therefore the aminomethylene group may be compared with an acid amide. The carbon linked to the imino and thio groups in thiazolidine compounds is lacking in the ability to hold these two groups with adequate strength. However, acylation of the imino group suffices to again reduce the strength of the carbon-sulfur bond, and such compounds are already not susceptible to oxidation by iodine. Consequently the acyl group acquires a considerable proportion of the bond energy from the imino group, and it is therefore probable that the bond between nitrogen and carbon is weakened and that between carbon and sulfur is strengthened.

EXPERIMENTAL

N-(2'-Phenyl-5(4)'-oxazolonemethylene-4')-thiazolidine-4-carboxylic acid. 1 g thiazolidine-4-carboxylic acid, 1.6 g 4-ethoxymethylene-2-phenyl-5(4)-oxazolone and 5 ml dry pyridine are stood overnight with periodic stirring. The crystalline precipitate is filtered, washed with ether, and twice recrystallized from acetone: m.p. 158-160° (with decomp.).

The prepared pyridinium salt in 200 ml ether is treated with 10% sulfuric acid. The ethereal solution is washed with water, dried with magnesium sulfate, and the ether distilled off. The residual solid is recrystallized twice from acetone; lustrous yellow crystals with m.p. 209-211° (with decomp.).

6.390 mg substance: 0.525 ml N_2. 6.230 mg substance: 0.516 ml N_2. Found %: N 9.35, 9.47. $C_{14}H_{12}O_4N_2S$. Calculated %: N 9.21.

0.1698 g N-(2'-phenyl-5(4)'-oxazolonemethylene-4')-thiazolidine-4-carboxylic acid is dissolved in 5 ml 4% ammonia solution. After a few minutes white crystals begin to come down. After two hours the mass thickens. The precipitate is filtered, washed with water and dried at 60°. Yield 0.1055 g 4-aminomethylene-2-phenyl-5(4)-oxazolone with m.p. 214-215°. This compound does not depress the melting point of an authentic specimen prepared by the action of alcoholic ammonia on 4-ethoxymethylene-2-phenyl-5(4)-oxazolone.

N-(2'-Phenyl-5(4)'-oxazolonemethylene-4')-2-benzylthiazolidine-4-carboxylic acid. 1 g 2-benzylthiazolidine-4-carboxylic acid, 1 g 4-ethoxymethylene-2-phenyl-5(4)-oxazolone and 5 ml dry pyridine are stood for 24 hours. The precipitate dissolves completely. The reaction mass is diluted with 300 ml ether; the ethereal solution is washed with 2 N phosphoric acid, then with water, and dried with magnesium sulfate. The ether is distilled off to leave a volume of 10-15 ml and the crystals are filtered and washed with ether before recrystallization from acetone. Yield 1.1 g of light-yellow needles with m.p. 190° (with decomp.).

6.690 mg substance: 0.430 ml N_2. Found %: N 7.09. $C_{21}H_{18}O_4N_2S$. Calculated %: N 7.10.

The pyridinium salt was prepared by dissolving acid (II) in a small amount of pyridine. It was recrystallized from a little acetone. Yellow crystals, m.p. 148-150° (with decomp.).

6.015 mg substance: 0.490 ml N_2. 7.515 mg substance: 0.600 ml N_2. Found %: N 8.88, 8.70. $C_{26}H_{23}O_4N_3S$. Calculated %: N 8.87.

Ammonium salt of (II). 0.5 g (II) is dissolved in 30 ml methyl alcohol and a small quantity of strong aqueous ammonia is added until the reaction is weakly alkaline. Microscopic platelets rapidly come down: m.p. 200-204° (with decomp.). Poorly soluble in water.

0.5 g of (II) was treated with 10 ml 25% ammonia solution. The precipitate did not dissolve in the ammonia but gradually acquired a pistachio color. After 10 days the precipitate was filtered and recrystallized from methyl alcohol; m.p. 215-216° (with decomp.). It did not depress the melting point of 4-aminomethylene-2-phenyl-5(4)-oxazolone.

0.1 g of (II) was dissolved in 10 ml ethyl alcohol. The compound was not oxidized when 0.1 g of iodine solution was added.

SUMMARY

Condensation products were prepared from thiazolidine-4-carboxylic acid and its derivatives with 4-ethoxymethylene-2-phenyl-5(4)-oxazolone and consisted of N-(2'-phenyl-5(4)'-oxazolonemethylene-4')-thiazolidine-4-carboxylic acid or its 2-substituted derivatives.

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THE SULFONATION REACTION

XXIV. HYDROLYSIS OF NAPHTHALENE DISULFONIC ACIDS

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The sulfonation of naphthalene at low temperatures is known to yield a mixture of 1,5-, 1,6- and 1,7-naphthalene disulfonic acids [1], whereas at a temperature of 160-180° 2,6-, 2,7-, 1,7- and 1,6-disulfonic acids are formed [2]. Moreover, at 130° the 1,3-disulfonic acid is formed in addition to other sulfonic acids [3]. The quantitative composition of the mixtures has not previously been accurately determined, due mainly to the lack of reliable methods of determination of the individual isomers in a mixture, and also to the constant change in the ratios between the isomers in various reaction conditions.

We believe that the main cause of the change of composition of the sulfonic acid mixtures resides in the different stabilities to desulfurization of the isomers entering into the composition of the sulfonic acid mixtures. If we knew the relative stabilities of the isomers, we could proceed to a systematic investigation of the composition of the sulfonic acid mixtures. This investigation was undertaken with that objective.

It is known that the compounds most stable to hydrolysis are 2,6- and 2,7-naphthalene disulfonic acids; here both the sulfo groups are in the β-position, whereas other isomers containing one or both sulfo groups in the α-position are less stable. It appears from the results of two researches by American authors [4,5] that at 120° and 140° the 1,5-disulfonic acid is less readily hydrolyzed than the 1,6-acid, but this appears improbable because the 1,5-isomer has both sulfo groups in the α-position.

In these researches the hydrolysis was performed in presence of sulfuric acid of definite concentrations, but the invariable presence of the hydrolyzing agent (water) was ignored. This is one of the sources of error. Moreover, the American authors arrived at the erroneous conclusion that the reaction does not proceed stepwise and that the sulfo groups are split off simultaneously [6] without intermediate formation of monosulfonic acids.

In a study of the desulfurization of four naphthalene disulfonic acids, Lantz [7] found that that 2,6- and 2,7-disulfonic acids are desulfurized with the same velocity. The 1,5- and 1,6-isomers are also desulfurized with identical velocities but much more readily than the 2,6- and 2,7-isomers

We have investigated the relative resistance to hydrolysis of all the six naphthalene disulfonic acids formed by direct sulfonation. We endeavored to perform a series of experiments in conditions close to those in which the formation and rearrangement of the isomers occurs, i.e. in presence of sulfuric acid. However, the concentration of the latter must not reach such values that the naphthalene formed on hydrolysis is resulfonated. In order to find the concentration of sulfuric acid permissible for hydrolysis, a series of experiments on the sulfonation of naphthalene and of naphthalene β-sulfonic acid was carried out. Results are presented in Tables 1 and 2.

The first two experiments of Table 1 showed that 60-66% sulfuric acid does not sulfonate naphthalene to a substantial extent at 160° because the naphthalene does not dissolve in acid of this concentration [8].

In presence of a sulfonic acid, however, naphthalene is soluble in the mixture. Experiments 157 and 158, carried out in presence of m-benzene disulfonic acid, which is not sulfonated or hydrolyzed in these conditions, showed that naphthalene is sulfonated by 50% sulfuric acid with considerable speed. In the experiments on hydrolysis at 160°, therefore, sulfuric acid was not used in concentrations higher than 45% in order to exclude or reduce to a minimum the possibility of resulfonation of the naphthalene. Table 2 contains data for the sulfonation of naphthalene β-sulfonic acid at a temperature of 100°; these data show that only 66% sulfuric acid is substantially without sulfonating action on the β-acid.

Experiments on the hydrolysis of naphthalene disulfonic acids at a temperature of 161° are detailed in Table 3. The first series of experiments was performed in the absence of sulfuric acid, the second and third series in presence of 35 and 45% sulfuric acid, and in each case in presence of about 9 mole water per mole of disulfonic acid. The experiments show that the disulfonic acids can be arranged in the following order in respect of resistance to hydrolysis:

2,6- > 2,7- > 1,3- > 1,7- > 1,6- > 1,5-

In this series the 2,6- and 2,7- isomers differ markedly from the other isomers. They are many times more stable than the disulfonic acids with the sulfo group in the α-position. The 1,5-disulfonic acid also differs considerably from the α- and β-acids. It is substantially completely decomposed in the described conditions and is therefore not present in the sulfonic acid mixtures prepared at 160°.

TABLE 1

Sulfonation of Naphthalene at 161° ± 1°

Expt. No.	Taken				Duration (hours)	% Conc. of sulfuric acid in mixture	Amount of sulfuric acid reacted (%)
	m-Benzene disulfonic acid (g)	Naphthalene (g)	Sulfuric acid (g)	Water per mole disulfonic acid (moles)			
140a	–	1.01	3.214	–	18	60.2	0.4
140b	–	1.38	4.442	–	4	66.1	0.0
157	0.3189	0.5	–	8.76	20	58.9	26.8
158	0.3257	0.5	–	9.71	20	49.9	14.2

TABLE 2

Sulfonation of Naphthalene-Sulfonic Acid at 100° for 25 hours*

Expt. No.	Moles water in mixture per mole sulfonic acid	% Conc. of sulfuric acid	Amount of β-acid sulfonated (in %)	Conc. of H_2SO_4 in mixture after expt (%)
194	4.75	78.1	37.8	74.4
195	4.55	74.8	16.5	72.8
196	4.51	70.2	2.7	69.8
197	4.42	66.1	0.4	65.8

In Table 4 are presented the results of experiments at 124°. At this temperature the 2,6- and 2,7-isomers are hydrolyzed extremely slowly, so that no experiments were performed with them. The isomers containing the sulfo group in the α- and β-position are hydrolyzed almost exclusively to the monosulfonic acid, i.e. they only split off the sulfo group in the α-position, whereas the 1,5-acid in presence of sulfuric acid is hydrolyzed preferentially to naphthalene.

At a temperature of 100° the hydrolysis of the disulfonic acids proceeds very slowly (Table 5). On changing from 45% sulfuric acid to 65%, the speed of hydrolysis is roughly doubled.

Whereas at a temperature of 125° only α-β-disulfonic acids are hydrolyzed to monosulfonic acid, at 100° all the sulfonic acids containing a sulfo group in the α-position lose only one sulfo group in the described conditions. The order of stability of the isomers to hydrolysis remains the same in all cases as above.

Finally, experiments were performed on heating of the 1,5-disulfonic acid with 60 % sulfuric acid at a temperature of 64° for periods of 40 and 120 hours. Analysis of the mixture showed, however, that the acid is not appreciably hydrolyzed in these conditions.

Consequently, the statement of Ambler and Scanlan [6] concerning the simultaneous removal of both sulfo groups is in conflict with our experimental results. The American authors were unable to detect any traces of the β-sulfonic acid during hydrolysis of the 1,6-disulfonic acid [6]. We performed an experiment on the hydrolysis of the 1,6-acid by heating in 35% sulfuric acid at 160° for 5 hours. After determination of the naphthalene in the mixture, a part of the solution was analyzed as described below, and another portion was analyzed for the β-sulfonic acid content by the method of Chuksanova and Bilik [9], involving salting-out with common salt and reprecipitation in the form of the benzidine salt. It was found that 5.3% of disulfonic acid was hydrolyzed to naphthalene and 50.7% to monosulfonic acid. The amount of β-sulfonic acid in the form of the benzidine salt was also found to be 50.7%.

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* To an accurately weighed sample of 0.4-0.6 g of β-acid, was added the calculated amount of sulfuric acid.

TABLE 3

Hydrolysis of Naphthalene Disulfonic Acids at a Temperature of 161° ± 1°

Expt. No.	Isomer	Duration of heating (hours)	Moles water per mole disulfonic acid	Conc. of sulfuric acid in mixture		% of original disulfonic acid hydrolyzed	
				initial	final	to naphthalene	to monosulfonic acid
230	2,6-	25	9.14	0		traces	2.0
229	2,7-	25	9.10	0		traces	3.5
162	1,3-	25	8.86	0	36.0	21.9	39.4
161	1,7-	25	8.89	0	40.7	20.1	59.1
160	1,6-	25	8.97	0	44.1	26.0	61.4
159	1,5-	25	9.04	0	58.9	97.1	–
184	2,6-	75	9.00	34.1	40.2	5.3	12.1
185	2,7-	75	9.10	34.9	45.1	9.9	21.4
170	1,3-	5	9.04	34.2	41.8	2.7	23.7
174	1,7-	5	9.18	35.0	51.5	traces	62.0
168	1,6-	5	8.99	34.4	51.8	5.9	64.1
173	1,5-	5	8.84	35.0	64.9	61.0	37.0
191	2,6-	25	8.94	45.8	47.9	2.5	5.9
190	2,7-	25	8.95	45.2	48.3	3.6	8.0

TABLE 4

Hydrolysis of Naphthalene Disulfonic Acids at 124° ± 1° for 25 hours

Expt. No.	Isomer	Moles water per mole disulfonic acid	Conc. of sulfuric acid in mixture		% of disulfonic acid hydrolyzed	
			initial	final	to naphthalene	to monosulfonic acid
178	1,3-	8.93	–	–	traces	1.1
177	1,7-	9.01	–	–	traces	1.9
176	1,6-	9.04	–	–	0	5.3
175	1,5-	9.14	–	–	3.0	3.5
182	1,3-	9.04	34.6	36.6	traces	7.3
181	1,7-	8.94	33.8	37.0	traces	10.8
180	1,6-	9.24	35.9	39.7	0.4	14.1
179	1,5-	9.45	34.4	46.1	21.6	6.6

TABLE 5

Hydrolysis of Naphthalene Disulfonic Acids at 100° ± 0.5° for 100 hours

Expt. No.	Isomer	Moles water per mole disulfonic acid	Conc. of sulfuric acid in mixture		% of disulfonic acid hydrolyzed	
			initial	final	to naphthalene	to monosulfonic acid
189	1,3-	9.08	45.0	–	none	2.8
188	1,7-	8.95	44.9	–	none	3.6
187	1,6-	9.23	45.4	–	traces	3.6
186	1,5-	9.13	45.3	–	traces	5.4
201	1,3-	8.93	65.8	66.3	none	5.5
200	1,7-	8.97	65.2	65.8	none	7.0
199	1,6-	9.09	64.8	65.4	none	7.2
198	1,5-	9.22	65.1	65.8	traces	8.0

EXPERIMENTAL

All the hydrolysis experiments were performed in sealed tubes which were heated in batches of 2,4 or 6 in an Eyckman apparatus with the vapors of butyric acid, ethyl butyrate and water. Starting materials were the free disulfonic acids prepared by hydrolysis in an aqueous alcoholic medium of the corresponding disulfochlorides. They were identified by their melting points. After hydrolysis, the contents of the tubes were poured into water and the naphthalene filtered through a small porcelain crucible with a perforated bottom. The precipitate was dried over lumps of sodium hydroxide in a desiccator saturated with naphthalene vapor. Blank experiments showed that the loss is about 0.003 g for a sample of naphthalene weighing about 0.2 g. This correction was introduced into the determination.

Following the removal of the naphthalene, the sulfuric acid in the filtrate was determined gravimetrically as barium sulfate. The increase in the amount of sulfuric acid after hydrolysis and the weight of separated naphthalene enabled calculation of the amount of disulfonic hydrolyzed to naphthalene and to monosulfonic acid.

SUMMARY

1. Six isomeric naphthalene disulfonic acids formed by direct sulfonation of naphthalene were subjected to hydrolysis at temperatures of 161,124 and 100° in water and in sulfuric acid with concentrations of 35 to 65%.

The disulfonic acids exhibit the following order of stability to hydrolysis: 2,6- > 2,7- > 1,3- > 1,7- > 1,6- > 1,5-.

2. Hydrolysis proceeds stepwise. At first one sulfo group is split off to form a monosulfonic acid which then hydrolyzes to naphthalene.

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SYNTHESIS OF N-OXIDES OF PHENAZINE DERIVATIVES

I. MONO-N-OXIDES OF ALKOXYPHENAZINES

V. P. Chernetsky and A. I. Kiprianov

N-Oxides of phenazine derivatives have been little investigated. Mono-N-oxides of phenazine were prepared for the first time by Wohl [1] in 1901 by alkaline condensation of nitrobenzene with aniline, but Wohl failed to obtain N-oxides by direct oxidation of phenazine. This was accomplished in 1938 by Z. V. Pushkareva and G. I. Agibalova [2] who obtained di-N-oxides of phenazine for the first time by oxidizing phenazine with perbenzoic acid in chloroform. Other investigators [3,4] prepared several mono- and di-N-oxides of phenazine derivatives (mono-N-oxides of 2,6-dihaloderivatives of phenazine, the di-N-oxide of 2-chlorophenazine, etc.).

In 1949 A. I. Kiprianov, S. B. Serebryanyi and V. P. Chernetsky established the structure [5] and effected the synthesis [6] of the natural pigment, iodinin – the di-N-oxide of 1,5-dihydroxyphenazine.

The present paper relates to a series of mono-N-oxides of alkoxyphenazines not previously described in the literature: mono-N-oxides of 1-methoxyphenazine, 1-ethoxyphenazine, 1,5-diethoxyphenazine, 1,6-diethoxyphenazine, 1,7-dimethoxyphenazine, 1,8-diethoxyphenazine and 2,6-dimethoxyphenazine (see table).

All the mono-N-oxides, with exception of (VII), were prepared by direct oxidation of the corresponding bases with hydrogen peroxide in acetic acid or with perbenzoic acid in benzene. The synthesis of the bases has been already described in publications from our laboratory [7,8,9]; some of them were kindly placed at our disposal by S. B. Serebryanyi to whom we take this opportunity of expressing our thanks.

2,6-Dimethoxyphenazine mono-N-oxide (VII) was prepared directly by alkaline condensation of p-nitroanisole with p-anisidine. It should be noted that mono-N-oxides are nearly always formed in the alkaline condensation of aromatic amines with aromatic nitro compounds, with the aim of preparing phenazine derivatives.

Direct oxidation of bases with perbenzoic acid, in the case of some phenazine derivatives, gives both mono-N-oxides and di-N-oxides.

Fractionation and purification of the prepared N-oxides was effected by chromatography on alumina followed by crystallization. When washing out the column with solvent, the compounds were always washed out in a definite sequence. The unoxidized base was the first to be washed out from the bottom pale-yellow band; then the mono-N-oxide was extracted from the following bright-yellow band. In some cases there was a red band of di-N-oxide higher up.

The mono-N-oxides have fairly high solubility in organic solvents. The yellow solutions exhibit an intense green fluorescence. They are sparingly soluble in water. Dialkoxyphenazine mono-N-oxides are less soluble than monoalkoxyphenazine mono-N-oxides. The mono-N-oxides dissolve in dilute acids with a red color.

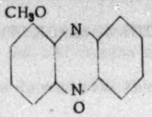
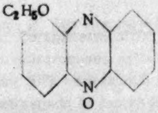
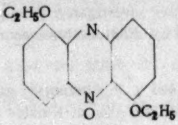
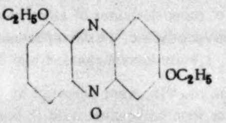
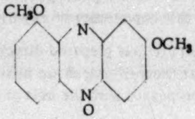
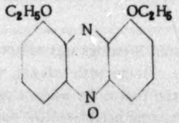
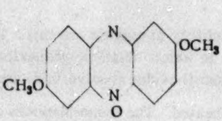
All the N-oxides are decomposed when heated. The mono-N-oxides of monoalkoxyphenazines have a melting point 10-15° lower than the decomposition temperature.

EXPERIMENTAL

1-Methoxy- and 1-ethoxyphenazines were oxidized in the following manner.

A weighed amount of the base was dissolved in glacial acetic acid in a vessel equipped with stirrer, reflux condenser and dropping funnel. The solution was heated on a water bath to 50-55° and addition made in several portions in the course of 10-12 hours of 10-20 times the amount (calculated on the base) of a 30% solution of hydrogen peroxide. The solution gradually darkened. After 15 hours the dark liquid was run off into 5 times the amount of water. The precipitate was filtered, and washed with dilute acetic acid and water. The dried oxidation product was dissolved in chloroform, filtered from undissolved impurities and the chloroform evaporated. Depending upon the purity, the product either crystallized or was subjected to supplementary chromatographic treatment on alumina.

Mono-N-oxides of Alkoxy Derivatives of Phenazine

Prep. No.	Name of base	Formula of mono-N-oxide	Melting and decomposition point	Appearance
I	1-Methoxyphenazine		196-198° (m.p.) 210° (decomp.)	Greenish-yellow platelets
II	1-Ethoxyphenazine		181-182° (m.p.) 214-217° (decomp)	Yellow needles
III	1,5-Diethoxyphenazine		170-172° (decomp)	Orange-yellow needles
IV	1,6-Diethoxyphenazine		207-209° (decomp)	Bright-yellow needles
V	1,7-Dimethoxyphenazine		227-229° (decomp)	Golden yellow needles
VI	1,8-Diethoxyphenazine		218-222° (decomp)	Yellow platelets
VII	2,6-Dimethoxyphenazine		233-235° (decomp)	Yellow silky needles

1-Methoxyphenazine mono-N-oxide (I). 0.5 g 1-methoxyphenazine was oxidized using 10 ml glacial acetic acid and 10 ml 30% hydrogen peroxide. After evaporation of the chloroform there remained reddish-yellow leaflets. Weight 0.3 g (58.5% of theory), m.p. 185-190°, decomp. pt. 208-210°. Recrystallization from hot water gave golden yellow platelets (the color changed to dull orange on drying), m.p. 196-198°, decomp.pt. 210°[*].

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[*] All temperature values are corrected. The melting point of the preparations was determined twice: once with rapid heating the melting point was observed approximately; the second time the apparatus was heated to a temperature 5-10° lower; the thermometer and capillary were then inserted and the temperature raised at the rate of 1° per minute until the substance decomposed.

Found %: N 12.20, 12.37*. $C_{13}H_{10}O_2N_2$. Calculated %: N 12.39.

1-Ethoxyphenazine mono-N-oxide (II). 0.5 g 1-ethoxyphenazine was oxidized in 10 ml glacial acetic acid with 10 ml 30% hydrogen peroxide. The residue after removal of the chloroform consisted of red-brown crystals. Weight 0.38 g. The melting point was gradual (90-160°). It was dissolved in benzene and chromatographed on alumina. After distilling off the benzene in vacuum, the residue was dried in the air. Weight 0.25 g (46.5% of theory), m.p. 176-180° decomp. pt. 214-217°. Clusters of slender yellow needles were formed from hot water with addition of alcohol: m.p. 181-182°, decomp. pt. 214-217°.

Found %: N 11.54, 11.63. $C_{13}H_{12}O_2N_2$. Calculated %: N 11.66.

Preparation of mono-N-oxides of (III), (IV), (V), (VI). 1,5$_2$-, 1,6-, 1,8-diethoxyphenazines and 1,7-dimethoxyphenazine were oxidized with perbenzoic acid in dry benzene. Weighed amounts of the bases were dissolved in benzene, the amount of the latter varying with the solubility of the substances. To the benzene solutions of the bases was added a benzene solution of perbenzoic acid containing 4-g-equivalents of acid. The mixture was stood at room temperature for 5 days. The yellow solutions gradually turned red-orange and small precipitates came down. At the end of 5 days the benzene solutions of the oxidation products were filtered and chromatographed in columns with alumina. On washing the columns with solvent (benzene, chloroform, dichlorethane) in all cases the chromatogram contained at the bottom a pale-yellow band of base, above this a bright-yellow band of mono-N-oxide and, in some cases, still higher up a small red band of di-N-oxide. Solutions of the substances washed out of the columns were collected separately. The solvent was distilled off in vacuum and the residue evaporated in the air. The products were crystallized from chloroform or aqueous alcohol. Chromatography and crystallization were repeated in some cases to obtain pure substances.

1,5-Diethoxyphenazine mono-N-oxide (III). 0.2 g 1,5-diethoxyphenazine in 100 ml benzene was oxidized with 0.5 g perbenzoic acid in 10 ml benzene. After two chromatographic treatments there was obtained 85 mg (40% of theory) of yellow-orange needles. M.p. 170-172° (with decomp). Found %: N 9.82 , 9.64. $C_{16}H_{16}O_3N_2$. Calculated %: N 9.85.

1,6-Diethoxyphenazine mono-N-oxide (IV) 0.2 g 1,6-diethoxyphenazine in 50 ml benzene was oxidized with 0.5 g perbenzoic acid in 10 ml benzene. Yield 145 mg (68.5% of theory) of yellow crystals. M.p. 185° (with decomp). The substance was twice recrystallized, once from aqueous acid and then from aqueous alcohol, forming clusters of bright-yellow needles. M.p. 207-209° (with decomp). Found %: N 10.02, 10.06. $C_{16}H_{16}O_3N_2$. Calculated %: N 9.85.

1,7-Dimethoxyphenazine mono-N-oxide (V). 0.2 g 1,7-dimethoxyphenazine in 50 ml benzene was oxidized with 0.5 g perbenzoic acid in 10 ml benzene to give 76 mg (35.5% of theory) of a yellow compound. M.p. 205-210° decomp. pt. 220°. Two crystallizations from aqueous alcohol gave clusters of golden yellow needles. M.p. 227-229° (with decomp). Found %: N 11.09, 11.12. $C_{14}H_{12}O_3N_2$. Calculated %: N 10.98.

1,8-Diethoxyphenazine mono-N-oxide (VI). 0.2 g 1,8-diethoxyphenazine in 100 ml benzene was oxidized with 0.5 g perbenzoic acid in 10 ml benzene to give 160 mg (75.5% of theory) of a brown crystalline substance. M.p. 208-210° (with decomp). From aqueous alcohol: golden yellow platelets with m.p. 218-222° (with decomp). Found %: N 9.79, 9.94. $C_{16}H_{16}O_3N_2$. Calculated %: N 9.85.

2,6-Dimethoxyphenazine mono-N-oxide (VII). 10 g p-nitroanisole was mixed with 10 g p-anisidine and the mixture was fused. To the fused mixture with energetic shaking was added in small portions 40 g potassium hydroxide powder. The mixture heated up considerably during addition of the alkali and darkened. The reaction vessel was cooled by running water in order to prevent the temperature from rising above 100°. After addition of the whole of the alkali and cooling of the reaction mass to room temperature, the mass was kept for 10 days. At the end of this period the mass was steam-distilled. The residue in the flask was cooled and the solid product filtered from the aqueous alkaline mother liquor. The solid, nearly black, product was dried and chromatographed from chloroform solution in a column with alumina. 1.75 g (10.5%) of mono-N-oxide fraction was obtained as orange-yellow crystals with m.p. 230-232° (with decomp). Crystallization from chloroform gave yellow silky needles melting at 233-235° (with decomp).

Found %: N 10.96, 10.72. $C_{14}H_{12}O_3N_2$. Calculated %: N 10.98.

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* Nitrogen was determined by microanalysis.

SUMMARY

1. The corresponding mono-N-oxides were prepared by oxidation of 1-ethoxyphenazine with hydrogen peroxide in acetic acid and of 1,5-, 1,6-, 1,8-diethoxyphenazines and of 1,7-dimethoxyphenazine with perbenzoic acid in benzene.

2. Alkaline condensation of p-nitroanisole with p-anisidine gave the mono-N-oxide of 2,6-diemthoxyphenazine.

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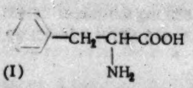
* See Consultants Bureau translation, p. 1691.

** See Consultants Bureau translation, p. 2265.

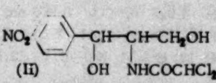
SYNTHESIS OF SOME ANALOGS OF PHENYLALANINE

M. N. Shchukina and T. P. Sycheva

A comparison of the formulas of one of the most important metabolites of the animal organism, phenylalanine (I), and chloromycetin (II) shows that these substances have very similar structures.



(I)



(II)

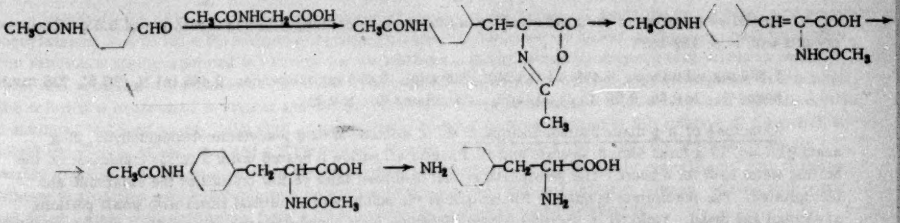
In this connection we planned to introduce into the phenylalanine molecule some functional groups characteristic of chloromycetin. In particular it was of interest to synthesize a phenylalanine containing a nitro group in the para-position of the aromatic nucleus and a dichloroacetyl residue at the α-amino group.

Phenylalanine, the starting substance for this synthesis, was prepared by the known method from α-acetaminocinnamic acid [1]. Reduction of α-acetaminocinnamic acid was effected by catalytic hydrogenation in presence of skeletal nickel catalyst in an autoclave at 70-90° and a hydrogen pressure of 25-30 atm. Nitration of phenylalanine was performed with fuming nitric acid in presence of concentrated sulfuric acid [2] at 0°. p-Nitro-N-dichloroacetylphenylalanine was prepared by the action of an ethereal solution of dichloracetyl chloride on an aqueous alcoholic solution of p-nitrophenylalanine.

At the end of 1950, after our investigation had been completed, a paper was published by Woolley [3] in which the author details the synthesis of some analogs of phenylalanine and, in particular, of p-nitro-N-dichloroacetylphenylalanine. He prepared this substance by nitration of N-dichloroacetylphenylalanine. It had m.p. 177-179°. In support of the structure, the author only gave the nitrogen determination without weights. The wide discrepancy between the melting points of our substance (169-170°) and that synthesized by Woolley remains mysterious, all the more since reduction of the p-nitro-N-dichloroacetylphenylalanine prepared by us led to the formation of p-amino-N-dichloroacetylphenylalanine.

In connection with the fact that the presence of an amino group in the aromatic nucleus has great significance for the antitubercular action of preparations, it appeared expedient to introduce this group into the phenylalanine molecule together with the dichloroacetyl residue.

p-Aminophenylalanine has up to now been prepared only by reduction of p-nitrophenylalanine [2]. We have developed a more convenient method of preparation from p-acetaminobenzaldehyde. The synthesis is represented by the following scheme:



p-Acetaminobenzaldehyde, prepared by the method evolved in our laboratory [4], reacts with acetylglycine to form the azlactone of α,p-diacetaminocinnamic acid, saponification of which yields the acid. α,p-Diacetaminocinnamic acid was hydrogenated with hydrogen in presence of skeletal nickel catalyst at 80-100° and 30 atm in sodium bicarbonate solution, forming p-acetamino-N-acetylphenylalanine; this is converted by acid hydrolysis into p-aminophenylalanine. Treatment of p-aminophenylalanine with dichloracetyl chloride gave p-dichloroacetamino-N-dichloroacetylphenylalanine.

In addition to the compounds mentioned above, the methyl esters of p-nitro-N-dichloroacetylphenylalanine and p-dichloroacetamino-N-dichloroacetylphenylalanine were prepared.

EXPERIMENTAL

p-Nitro-N-dichloroacetylphenylalanine. To a solution of 1.4 g p-nitrophenylalanine in 25 ml 1 N sodium hydroxide solution is gradually added, with ice-water cooling and stirring, 1.5 g dichloroacetyl chloride in 10 ml ether. After the addition, the flask contained a fairly large precipitate. The mixture is stirred for another 20 minutes, after which the ether is removed in vacuum. The precipitate dissolves during this operation. The solution is acidified with 10% hydrochloric acid until acid to congo and the precipitate is filtered off, washed with glacial acetic acid and dried. Yield 1.6 g, m.p. 164-169°. After recrystallization from aqueous alcohol, p-nitrodichloroacetylphenylalanine forms colorless crystals with m.p. 169-170°.

2.999 mg substance: 4.525 mg CO_2; 0.960 mg H_2O. 5.520 mg substance: 0.431 ml N_2 (23°, 733.0 mm). 3.040 mg substance: 2.735 mg AgCl. Found %: C 41.15; H 3.58; N 8.68; Cl 22.26. $C_{11}H_{10}O_5N_2Cl_2$. Calculated %: C 41.12; H 3.11; N 8.72; Cl 22.11.

Methyl ester of p-nitrophenylalanine hydrochloride. 2.62 g p-nitrophenylalanine and 25 ml 4.5% hydrogen chloride solution in methanol are heated at the boil on the water bath for 3 hours. The excess of hydrogen chloride and methanol is then driven off in vacuum to leave 3 g white crystals which were twice recrystallized from alcohol. M.p. 197°.

5.562 mg substance: 4.35 ml 0.01 N H_2SO_4 (Kjeldahl). Found %: N 10.94. $C_{10}H_{13}O_4N_2Cl$. Calculated %: N 10.74.

Methyl ester of p-nitro-N-dichloroacetylphenylalanine. To a solution of 3 g methyl ester of p-nitrophenylalanine hydrochloride in a little water is added dropwise an excess of 25% aqueous ammonia. The resultant oil is extracted with ether, the ethereal solution dried with sodium sulfate and the ether driven off in vacuum to leave 2.2 g of yellow oily material – the methyl ester of p-nitro-N-dichloroacetylphenylalanine. To this substance, dissolved in 15 ml ether is added gradually with cooling and stirring, alternately, a 2.5% solution of sodium hydroxide and a solution of 2 g dichloroacetyl chloride in 10 ml ether at such a rate that the reaction is weakly alkaline the whole time. At the conclusion of the reaction a white crystalline precipitate is formed which is filtered (after removal of ether), washed with 5% hydrochloric acid, then with 5% sodium carbonate and with water, and dried. Yield 2 g with m.p. 127-129°. After recrystallization from aqueous alcohol the methyl ester of p-nitro-N-dichloroacetylphenylalanine has m.p. 129-130°.

4.282 mg substance: 6.745 mg CO_2; 1.380 mg H_2O. Found %: C 42.96; H 3.60. $C_{12}H_{12}O_5N_2Cl_2$. Calculated %: C 42.98; H 3.58.

p-Amino-N-dichloroacetylphenylalanine. A solution of 1 g p-nitro-N-dichloroacetylphenylalanine in 20 ml ethyl alcohol is subjected to catalytic hydrogenation with hydrogen in presence of skeletal nickel catalyst at room temperature and atmospheric pressure. Hydrogen is absorbed slowly (in the course of 6 hours) and during the process a part of the formed substance crystallizes out. To the reaction mixture is added 15 ml alcohol, the mixture is heated to the boil and the catalyst is filtered from the hot solution.

Partial evaporation of the alcoholic solution,followed by cooling,results in separation of 0.5 g of faint-yellow crystals with m.p. 182-183°.

5.580 mg substance: 0.488 ml N_2 (240°, 726 mm). 5.485 mg substance: 0.488 ml N_2 (26.5°, 726 mm). Found %: N 9.60, 9.69. $C_{11}H_{12}O_3N_2Cl_2$. Calculated %: N 9.62.

Azlactone of α-p-diacetaminocinnamic acid. A mixture of 32 g p-acetaminobenzaldehyde, 25 g acetylglycine, 17 g fused sodium acetate and 56 g acetic anhydride is heated under a reflux condenser on the boiling water bath for 4 hours. The precipitate at first dissolves; later yellow crystals of the azlactone are precipitated. The precipitate is quickly filtered hot at the pump, washed several times with small portions of alcohol and dried. Yield 31 g. Several recrystallizations from aqueous alcohol give yellow crystals, insoluble in bicarbonate and water, readily soluble in alcohol, m.p. 230-232°.

3.365 mg substance: 7.845 mg CO_2; 1.529 mg H_2O. Found %: C 63.58; H 5.08. $C_{13}H_{12}O_3N_2$. Calculated %: C 63.90; H 4.95.

α,p-Diacetaminocinnamic acid. 1.33 g recrystallized azlactone of α,p-diacetaminocinnamic acid, 20 ml acetone and 7 ml water are boiled on the water bath for 8 hours. After the heating the whole of the azlactone goes into solution. The acetone and water are removed in vacuum and the residue dissolved in alcohol; the solution is decolorized with carbon, filtered and cooled with ice mixture. The separated crystals are filtered, washed with small amounts of alcohol and ether. Yield 1.05 g of α,p-diacetaminocinnamic acid with m.p. 240-241°. The acid crystallizes from aqueous alcohol with one molecule of water; from 96% alcohol it comes out without water of crystallization.

4.322 mg substance: 9.459 mg CO_2; 2.102 mg H_2O. 6.490 mg substance: 0.621 ml N_2 (22.0°, 726.0 mm). Found %: C 59.68; H 5.44; N 10.57. $C_{13}H_{14}O_4N_2$. Calculated %: C 59.54; H 5.34; N 10.68.

p-Acetamino-N-acetylphenylalanine. 12.75 g unrecrystallized α,p-diacetaminocinnamic acid is dissolved in 150 ml 3 % sodium bicarbonate solution. The slightly turbid yellow solution of the salt is decolorized with active carbon and subjected to catalytic hydrogenation in presence of skeletal nickel catalyst at 80-100° and 30 atm for 3 hours. After removal of the catalyst, the filtrate is evaporated in vacuum to a volume of about 40 ml, acidified with 10% hydrochloric acid until acid to congo, cooled with ice and filtered. The p-acetamino-N-acetylphenylalanine is washed with ice water. After drying in a vacuum desiccator, the acid had m.p. 208-210°; yield 11.35 g. After recrystallization from hot water the m.p. was 210-211°.

3.702 mg substance: 8.008 mg CO_2; 2.068 mg H_2O. Found %: C 59.00; H 6.25. $C_{13}H_{16}O_4N_2$. Calculated %: C 59.09; H 6.06.

p-Aminophenylalanine. A mixture of 1 g p-acetamino-N-acetylphenylalanine and 32 ml 1 N hydrochloric acid is heated to boiling for 20 hours. The solution is then evaporated in vacuum and the residual thick, caramelized syrup is treated with water several times and the latter then distilled off in vacuum. The hydrochloride is then dissolved in a small quantity of water and neutralized with ammonia. Acetic acid is added until the reaction is acid, when white crystals come down which are filtered, washed with a small quantity of ice water and dried.

After recrystallization from aqueous alcohol and drying in a vacuum desiccator at 100°, the substance has m.p. 221-222° (with decomp). According to the literature, p-aminophenylalanine melts at 245° (with decomp).

3.918 mg substance: 8.631 mg CO_2; 2.412 mg H_2O. Found %: C 59.60; H 6.89. $C_9H_{12}O_2N_2$. Calculated %: C 60.00; H 6.66.

p-Dichloroacetamino-N-dichloroacetylphenylalanine. To a solution of 2.5 g p-aminophenylalanine in 25 ml 2.5% NaOH with cooling and stirring, are alternately added a solution of 5.5 g dichloroacetyl chloride in 10 ml ether and a 2.5% aqueous solution of NaOH at such a rate that the reaction is alkaline over the whole period. During the reaction an oil is formed, which at the end crystallizes. The ether is removed in vacuum, the residue acidified with hydrochloric acid until it gives an acid reaction to congo, and the white precipitate is filtered, washed with ice water and dried in a vacuum desiccator. Yield 2.35 g.

After two recrystallizations, p-dichloroacetamino-N-dichloroacetylphenylalanine has m.p. 215-216°. White crystals, insoluble in hydrochloric acid and water, readily soluble in alcohol.

3.292 mg substance: 4.682 mg CO_2; 0.896 mg H_2O. 5.146 mg substance: 2.64 ml 0.01 N H_2SO_4. (Kjeldahl). Found %: C 38.79; H 3.04; N 7.18. $C_{13}H_{12}O_4N_2Cl_4$. Calculated %: C 38.80; H 2.98; N 6.96.

Methyl ester of p-dichloroacetamino-N-dichloroacetylphenylalanine. 4.3 g of the hydrochloride of p-aminophenylalanine and 25 ml 4.5% solution of hydrogen chloride in methanol, are boiled on the water bath for 6 hours. The solution is then evaporated in vacuum and the residue (a thick, caramelized syrup) is dissolved in 30 ml water and neutralized with aqueous ammonia. The ester of p-aminophenylalanine does not separate at this stage. The solution is evaporated to dryness and the resultant thick resin, contaminated with ammonium chloride crystals, is dissolved in 15 ml water. With cooling and stirring, alternate addition is made to this solution of 6.5 g dichloroacetyl chloride in 20 ml ether and a 2.5% aqueous solutinn NaOH, at such a speed that the reaction is always weakly alkaline. At the conclusion of the reaction an oil separates and immediately crystallizes. The reaction mixture is acidified with hydrochloric acid until acid to congo and the precipitate is filtered, washed with water and dried. After recrystallization from a little alcohol the substance melts at 175-176°.

4.111 mg substance: 6.121 mg CO_2; 1.279 mg H_2O. Found %: C 40.61; H 3.48. $C_{14}H_{14}O_4N_2Cl_4$. Calculated %: C 40.38; H 3.36.

SUMMARY

1. A series of new derivatives of phenylalanine containing the dichloroacetyl group has been prepared.

2. A new method for preparation of p-aminophenylalanine from p-acetaminobenzaldehyde has been developed.

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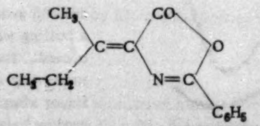
INVESTIGATIONS ON AMINO ACIDS

III. CIS-TRANS ISOMERISM IN THE OXAZOLONE (AZLACTONE) SERIES

S. I. Lurye and R. G. Vdovina

Workers [1] who investigated the condensation of ketones with hippuric acid arrived at the conclusion that certain ketones, including methylethyl ketone, do not react with the acid. Instead of the anticipated oxazolones, they obtained a compound with m.p. 138° and the empirical formula $(C_9H_7O_2N)_X$, apparently a product of condensation of hippuric acid molecules. However, when we condensed methylethyl ketone with hippuric acid we obtained, in place of the compound with m.p. 138°, a reddish-yellow oil which changed on standing into crystals with m.p. 33-37°. The empirical formula of this compound is $C_{13}H_{13}O_2N$. On the assumption that this is the sought for oxazolone (A), we decided to prepare the derivatives characteristic of the compounds of this group. On heating with alkali and aniline, an acid with the empirical formula $C_{13}H_{15}O_3N$ and the anilide of this acid with the empirical formula $C_{19}H_{20}O_2N_2$ were respectively obtained. Reduction of our compound in alcohol with hydrogen in presence of pyrophoric nickel gave α-amino-β-methylvaleric acid (isoleucine). The preparation of these derivatives confirmed our supposition that the product of condensation of methylethyl ketone with hippuric acid with the empirical formula $C_{13}H_{13}O_2N$ is 2-phenyl-4-isobutylidene-5-oxazolone (A).



(A)

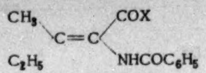
Further investigation of the oxazolone with m.p. 33-37° showed that it is a mixture of two geometrical isomers. Both isomers could be isolated by saponification of the oxazolone with an amount of alkali less than that theoretically required. In these conditions a portion of the product is saponified and goes into solution, while the unsaponified portion remains in the form of an oil which quickly crystallizes when cooled.

Acidification of the alkaline solution with hydrochloric acid causes separation of N-benzoylamino-β-methyl-β-ethylacrylic acid, which on heating with acetic anhydride is converted into 2-phenyl-4-isobutylidene-5-oxazolone with m.p. 52-54°. We designate this isomer (I)

A single crystallization of the crystalline unsaponified residue from alcohol gave a white crystalline compound with m.p. 63-64°. The analysis and properties of this compound corresponded to 2-phenyl-4-isobutylidene 5-oxazolone, which we call isomer (II). The melting point of a mixture of isomers (I) and (II) is 33-37°. More detailed characterization of the prepared isomers appeared of interest. With this objective we plotted the absorption spectra in the ultra-violet region and prepared some derivatives.

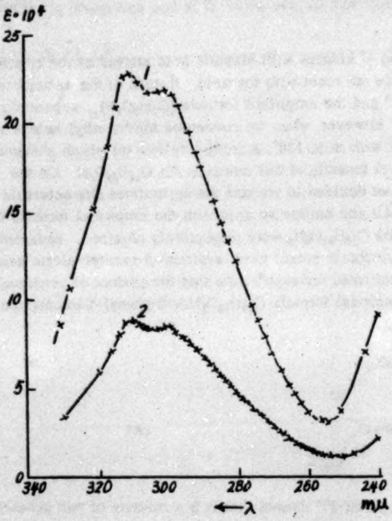
The absorption spectra of isomers (I) and (II) differ in intensity of absorption. The maxima of their spectra are nearly identical (see diagram). Saponification of oxazolones (I) and (II) with alkali yields two isomeric acids (Ia) and (IIa). These acids differ in melting points and in degree of solubility in alcohol; acid (Ia) is soluble in alcohol in the ratio of 1:40, acid (IIa) in the ratio of 1:10. When heated with acetic anhydride the acids revert to their respective oxazolones. When methyl alcohol in presence of a trace of sodium methylate, the oxazolones (I) and (II) form esters of N-benzoylamino-β-methyl-β-ethylacrylic acid (Ib) and (IIb). Treatment with piperidine gives two piperidides of N-benzoylamino-β-methyl-β-ethylacrylic acid, but it was impossible to establish which of these corresponded to oxazolone (I) and which to oxazolone (II). Aniline gave one isomer of the anilide of N-benzoylamino-β-methyl-β-ethylacrylic acid. The formation of only one isomer is evidently due to the ability of geometrical isomers to isomerize in presence of organic bases [3]; on the other hand two isomeric piperidides of the same acid were derived from each geometrical isomer of the oxazolone.

The following geometrical isomers have thus been prepared:



when X = OH geometrical isomers (Ia) and (IIa)
X = OCH_3 " " (Ib) and (IIb)
X = NC_5H_{10} " " (two)
X = NHC_6H_5 " " (one)

In Table 1 are presented the melting points of 2-phenyl-4-isobutylidene-5-oxazolones (I) and (II), and of some of their derivatives.



Ultraviolet absorption spectra of 2-phenyl-4-isobutylidene-5-oxazolone (in alcohol). 1) isomer (I) with m.p. 52-54°; 2) isomer (II) with m.p. 63-64°.

EXPERIMENTAL

1. 2-Phenyl-4-isobutylidene-5-oxazolone (mixture of isomers (I) and (II). 2-Phenyl-4-isobutylidene-5-oxazolone is prepared by heating methylethyl ketone, hippuric acid, acetic anhydride and sodium acetate [4]. The oxazolone, a dark-red oil, gradually crystallizes on standing. M.p. 33-37°. Yield 60-70 % of the theoretical.

Found %: C 72.43; H 6.07; N 6.56. $C_{13}H_{13}O_2N$. Calculated %: C 72.52; H 6.09; N 6.51.

2. Anilide of N-benzoylamino-β-methyl-β-ethylacrylic acid. 0.75 g 2-phenyl-4-isobutylidene-5-oxazolone (oil), 10 g dry benzene and 0.5 g freshly distilled aniline are heated on a boiling water bath for 30 minutes and then cooled. The crystals are filtered. A further small crop of crystals is got from the mother liquor after distilling off the benzene. The product crystallizes from a mixture of benzene and alcohol (1:2). After three recrystallizations the anilide of N-benzoylamino-β-methyl-β-ethylacrylic acid melts at 254-255°. Yield 70% of theory.

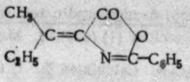
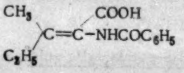
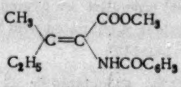
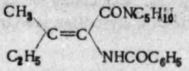
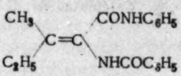
Found %: C 73.79; H 6.61; N 9.04. $C_{19}H_{20}O_2N_2$. Calculated %: C 73.98; H 6.54; N 9.09.

3. N-Benzoylamino-β-methyl-β-ethylacrylic acid (mixture of isomers). 20 g 2-phenyl-4-isobutylidene-5-oxazolone (oil or crystalline isomer with m.p. 33-37°) and 350 ml 2% sodium hydroxide solution are heated for 4 hours; a yellow solution is formed. After cooling, it is shaken with 100 ml ether, the ether is separated and to the remainder is added 10% hydrochloric acid until the reaction is acid to congo. A white crystalline substance comes down and gradually turns pink. It is filtered, washed with a little water and dried. The crystals are then heated with carbon tetrachloride, cooled and filtered. The residue is washed on the filter with a small amount of carbon tetrachloride and dried. The product crystallizes from alcohol with m.p. 198-200°. Yield 55% of theoretical.

Found %: C 66.77; H 6.24; N 6.01. $C_{13}H_{15}O_3N$. Calculated %: C 66.92; H 6.49; N 6.12.

4. α-Amino-β-methylvaleric acid (isoleucine). 20 g 2-phenyl-4-isobutylidene-5-oxazolone is dissolved in 50 ml alcohol; 7 g Raney nickel is added and reduction effected at 70-90° and an initial pressure of 80 atm. Absorption of the requisite amount of hydrogen is complete in 2 hours. At the end of the reaction the mass is filtered and the catalyst well washed with alcohol. The main alcoholic solution and the alcohol washings are combined and distilled to dryness in vacuum. The residue is boiled with 200 ml 17% hydrochloric acid for 7-9 hours. After cooling, the benzoic acid is filtered off. The hydrochloric acid solution is evaporated to dryness in vacuum. Water is twice added to the residue and the evaporation to dryness repeated. The dry residue is dissolved

TABLE 1

Prep. No.	Name	Formula	Melting point		
			of oxazolone (I) and its derivatives	of oxazolone (II) and its derivatives	of mixed specimens of the geom. isomers
1	2-Phenyl-4-isobutylidene-5-oxazolone		52-54°	63-64°	33-37°
2	N-Benzoylamino-β-methyl-β-ethylacrylic acid	 $(CH_3)(C_2H_5)C{=}C(COOH)NHCOC_6H_5$	223-224	200-204	198-200
3	Methyl ester of N-benzoylamino-β-methyl-β-ethylacrylic acid	 $(CH_3)(C_2H_5)C{=}C(COOCH_3)NHCOC_6H_3$	155-156	138-139	121-125
4	Piperidide of N-benzoylamino-β-methyl-β-ethylacrylic acid	 $(CH_3)(C_2H_5)C{=}C(CONC_5H_{10})NHCOC_6H_5$	141-143	178-179	134-140
5	Anilide of N-benzoylamino-β-methyl-β-ethylacrylic acid	 $(CH_3)(C_2H_5)C{=}C(CONHC_6H_5)NHCOC_6H_5$	254-255°		

The absorption spectra were plotted by Kh. M. Ravikovich to whom we convey our thanks.

in absolute alcohol, addition is made to the solution of diethylamine until the reaction is neutral (bromothymol blue), and the mass is left for 24 hours. It is then filtered and the α-amino-β-methyl-valeric acid is purified by dissolving in water and precipitation with alcohol. M.p. 276-279°. Yield 44% of theoretical.

Found %: C 54.81; H 9.94; N 10.58. $C_6H_{13}O_2N$. Calculated %: C 54.99; H 9.91; N 10.69.

5. 2-Phenyl-4-isobutylidene-5-oxazolone (isomer I). 20 g of the mixture of geometrical isomers (oil) is heated with 125 ml 2% sodium hydroxide solution for 4 hours. A solution and a rapidly crystallizing oily layer are formed. The solution is poured off from the crystals and treated with ether. After removing the ether, the alkaline solution is neutralized with 10% hydrochloric acid. The white precipitate is filtered off and heated with carbon tetrachloride. After filtering, the precipitate is crystallized three times from alcohol. N-Benzoylamino-β-methyl-β-ethylacrylic acid (Ia) melts at 223-224°. The acid is insoluble in water, poorly soluble in cold alcohol, and soluble in hot alcohol in the ratio of 1:40. 5 g N-benzoylamino-β-methyl-β-ethylacrylic acid is heated on the boiling water bath for 20 minutes with 25 ml acetic anhydride. On cooling, the acetic anhydride is distilled off in vacuum. The residue is crystallized from alcohol. M.p. of the oxazolone (I) 52-54°. Yield 70-75%.

Found %: C 72.35; H 6.04; N 6.31. $C_{13}H_{13}O_2N$. Calculated %: C 72.52; H 6.09; N 6.51.

6. Methyl ester of N-benzoylamino-β-methyl-β-ethylacrylic acid (isomer Ib). 1 g 2-phenyl-4-isobutylidene-5-oxazolone (I) is dissolved in 100 ml absolute methyl alcohol to which is added 4 mg metallic sodium, and left for 20-25 hours. The alcohol is then distilled off in vacuum to half the volume, neutralization is cautiously effected with a drop of hydrochloric acid and another portion of the alcohol is distilled off. The methyl ester of N-benzoylamino-β-methyl-β-ethylacrylic acid (Ib) is recrystallized from alcohol as white lustrous crystals. M.p. 155-156°.

Found %: C 67.85; H 6.88; N 5.45. $C_{14}H_{17}O_3N$. Calculated %: C 67.99; H 6.94; N 5.66.

7. 2-Phenyl-4-isobutylidene-5-oxazolone (isomer II). Heating of the mixture of geometrical isomers with alkali gives an alkaline solution and a crystalline yellowish-red substance (expt. 5). The crystalline substance is recrystallized several times from 70% alcohol; oxazolone (II) separates in the form of white needles with m.p. 63-64°.

Found %: C 72.30; H 5.83; N 6.45. $C_{13}H_{13}O_2N$. Calculated %: C 72.52; H 6.09; N 6.51. A mixed sample with isomer (I) melts at 33-37°. Heating of oxazolone (II) with 2% sodium hydroxide solution for $1\frac{1}{2}$ hrs giyes N-hebzoylamino-β-methyl-β-ethylacrylic acid with m.p. 202-204° (isomer IIa).

Found %: C 67.03; H 6.71; N 5.87; M 235.6. $C_{13}H_{15}O_3N$. Calculated %: C 66.92; H 6.49; N 6.01; M 233.12. A mixed sample with the isomeric acid (Ia) melts at 198-200°. Acid (IIa) changes into the oxazolone (II) when heated with acetic anhydride.

8. Methyl ester of N-benzoylamino-β-methyl-β-ethylacrylic acid (isomer IIb). This ester is prepared from oxazolone (II) in the same manner as from oxazolone (I) (expt.6). M.p. 138-139°.

Found %: C 67.92; H 6.88; N 5.94. $C_{14}H_{17}O_3N$. Calculated %: C 67.99; H 6.94; N 5.66.

A mixture of esters (Ib and IIb) melts at 121-123°.

9. Piperidides of N-benzoylamino-β-methyl-β-ethylacrylic acid. 0.85 g 2-phenyl-4-isobutylidene-5-oxazolone (isomer I or II), 5 ml dry benzene and 1 ml piperidine are heated on the boiling water bath for 1 hour. The benzene is then distilled off in vacuum. The residue is triturated with 5 ml dry ether and filtered. The precipitate is twice crystallized from alcohol. M.p. 141-143°.

Found %: C 71.69; H 7.78; N 9.55. $C_{18}H_{24}O_2N_2$. Calculated %: C 71.95; H 8.06; N 9.33. Removal of the ether from the ethereal mother liquor yields a crystalline substance. After 2 or 3 crystallizations from alcohol it melts at 178-179°.

Found %: C 72.26; H 8.10; N 9.50. $C_{18}H_{24}O_2N_2$. Calculated %: C 71.95; H 8.06; N 9.33. A mixture of the two piperidides melts at 134-140°.

SUMMARY

1. It is shown that methylethyl ketone reacts with hippuric acid to form 2-phenyl-4-isobutylidene-5-oxazolone (A).

2. The compound with m.p. 33-37° is shown to be a mixture of two geometrical isomers (I) and (II). The isomers were separated and some of their derivatives prepared.

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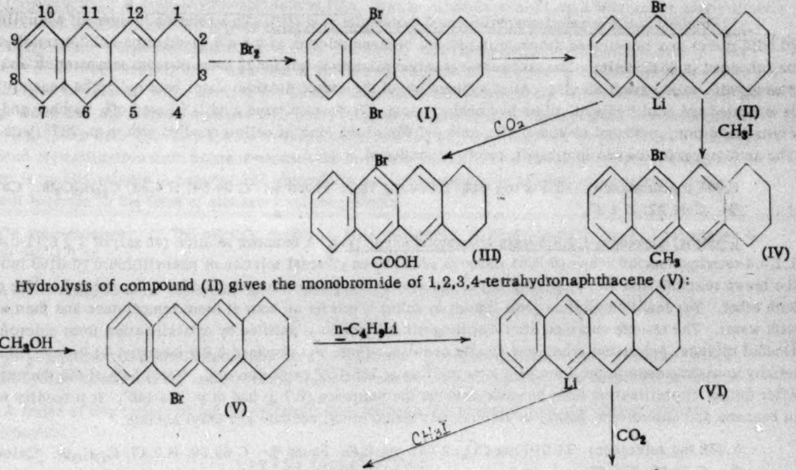
INVESTIGATIONS IN THE NAPHTHACENE SERIES

II. ORGANOLITHIUM COMPOUNDS OF 1,2,3,4-TETRAHYDRONAPHTHACENE AND THEIR TRANSFORMATIONS [1]

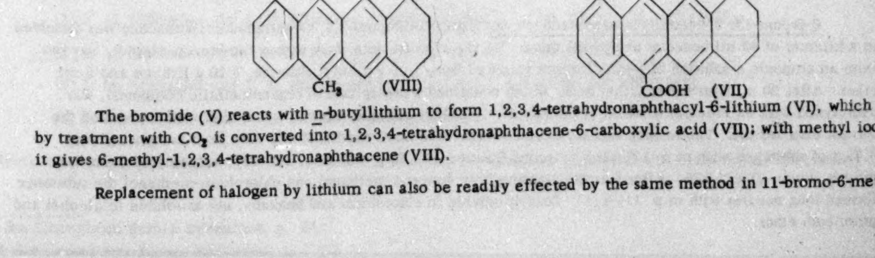
B. M. Mikhailov and A. D. Chinaeva

We have shown that the method of preparation of organolithium compounds consisting in reacting n-butyllithium or phenyllithium with aryl bromides can be successfully applied to a series of polynuclear condensed hydrocarbons — anthracene [2], 1,2-benzanthracene [3] and phenanthrene [4].

In this communication, we describe the preparation by this method of organolithium compounds of 1,2,3,4-tetrahydronaphthacene and their transformations leading to the synthesis of derivatives of the linear tetracyclic hydrocarbon. The starting material for this investigation was 6,11-dibrom-1,2,3,4-tetrahydronaphthacene (I), which is readily prepared by the action of two equivalents of bromine on 1,2,3,4-tetrahydronaphthacene. Reaction of phenyllithium with the dibromide of 1,2,3,4-tetrahydronaphthacene gives 6-bromo-1,2,3,4-tetrahydronaphthacyl-11-lithium (II). Compound (II) is converted by carboxylation into 11-bromo-1,2,3,4-tetrahydronaphthacene-6-carboxylic acid (III); reaction of the organo-metallic compound (II) with methyl iodide leads to formation of 11-bromo-6-methyl-1,2,3,4-tetrahydronaphthacene (IV):



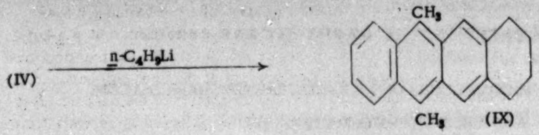
Hydrolysis of compound (II) gives the monobromide of 1,2,3,4-tetrahydronaphthacene (V):



The bromide (V) reacts with n-butyllithium to form 1,2,3,4-tetrahydronaphthacyl-6-lithium (VI), which by treatment with CO_2 is converted into 1,2,3,4-tetrahydronaphthacene-6-carboxylic acid (VII); with methyl iodide it gives 6-methyl-1,2,3,4-tetrahydronaphthacene (VIII).

Replacement of halogen by lithium can also be readily effected by the same method in 11-bromo-6-methyl-

1,2,3,4-tetrahydronaphthacene (IV). The resultant organolithium compound reacts with methyl iodide to form 6,11-dimethyl-1,2,3,4-tetrahydronaphthacene (IX):



(IX)

EXPERIMENTAL

All the operations with organolithium compounds were performed at atmospheric pressure.

6,11-Dibromo-1,2,3,4-tetrahydronaphthacene (I). To a cooled (to 0°) suspension of 7.5 g 1,2,3,4-tetrahydronaphthacene [1] in 375 ml carbon tetrachloride, placed in a three-necked flask fitted with dropping funnel, stirrer and reflux condenser, was added dropwise with stirring over a period of 40 minutes 12 g bromine diluted with 60 ml carbon tetrachloride. With progressive addition of bromine the 1,2,3,4-tetrahydronaphthacene went into solution and hydrogen bromide was evolved. After heating for 20 minutes on a water bath, the brown reaction mixture was filtered, the solvent distilled off and the residue recrystallized from benzene and then from chloroform-alcohol mixture. Yield 8.25 g 6,11-dibromo-1,2,3,4-tetrahydronaphthacene with m.p. 186-188°. The yield was equivalent to 65.4% of the theoretical.

The compound forms dark-yellow rhombic platelets, readily soluble in chloroform and benzene, poorly soluble in alcohol and ether.

7.252 mg substance: 14.659 mg CO_2; 2.312 mg H_2O. Found %: C 55.16; H 3.56. $C_{18}H_{14}Br_2$. Calculated %: C 55.39; H 3.61.

11-Bromo-1,2,3,4-tetrahydronaphthacene-6-carboxylic acid (III). To a solution in ether of phenyllithium (0.0012 mole) in a two-limbed ampoule is added a benzene solution of 0.5 g 6,11-dibromo-1,2,3,4-tetrahydronaphthacene (0.0012 mole). The transparent reaction mixture is left for $1\frac{1}{2}$ hours at room temperature and then poured onto solid carbon dioxide. After evaporation of the carbon dioxide, water is added. The aqueous layer is separated and acidified with dilute hydrochloric acid. The precipitated acid is filtered off, washed, and twice crystallized from methanol to give 0.15 g acid (32.6%) in the form of yellow needles with m.p. 227° (with decomp). The acid is readily soluble in ethanol, poorly in methanol.

6.587 mg substance: 15.532 mg CO_2; 2.548 mg H_2O. Found %: C 64.34; H 4.32. $C_{19}H_{15}O_2Br$. Calculated %: C 64.22; H 4.26.

6-Methyl-11-bromo-1,2,3,4-tetrahydronaphthacene (IV). A benzene solution (40 ml) of 2 g 6,11-dibromo-1,2,3,4-tetrahydronaphthacene (0.0051 mole) is added to an ethereal solution of phenyllithium (0.0103 mole). To the brown reaction mixture, after standing for an hour at room temperature, is added 2.3 g methyl iodide diluted with ether. The reaction mixture (now lighter in color) is left for an hour at room temperature and then washed with water. The residue obtained after distilling off the solvent is purified by crystallization from chloroform-alcohol mixture, petroleum ether, and finally acetone. There was obtained 0.9 g 6-methyl-11-bromo-1,2,3,4-tetrahydronaphthacene in the form of prisms melting at 135-136° (with decomp). Yield 54% of the theoretical. After further crystallization from benzene-acetone the substance (0.7 g) had m.p. 144-146°. It is readily soluble in benzene and chloroform, poorly in alcohol, petroleum ether, acetone and ethyl acetate.

5.468 mg substance: 14.010 mg CO_2; 2.658 mg H_2O. Found %: C 69.99; H 5.47. $C_{19}H_{17}Br$. Calculated %: C 70.15; H 5.27.

6-Bromo-1,2,3,4-tetrahydronaphthacene (V). 3 g 6,11-dibromo-1,2,3,4-tetrahydronaphthacene was dissolved in a mixture of 40 ml benzene and 20 ml ether. To the solution, in a flask with a two-branch adaptor, was run from an ampoule a solution of n-butyllithium prepared from 1.09 g n-butyl chloride, 0.16 g lithium and 5 ml ether. After 30 minutes the reaction mass, which contained a precipitate of organometallic compound, was hydrolyzed with an ethereal solution of methanol. The ether-benzene solution was washed with water and the solvent distilled off. The residue was crystallized from chloroform-methanol and then from acetone, giving 0.75 g of substance with m.p. 107-110°; a second fraction of 0.52 g with m.p. 103-105° was isolated from the mother liquor. Yield 53%. After recrystallization from benzene-methanol and chloroform-methanol, the substance formed long needles with m.p. 110-111°. Readily soluble in chloroform and benzene, not so soluble in alcohol and petroleum ether.

5.590 mg substance: 14.304 mg CO_2; 2.524 mg H_2O. Found %: C 69.83; H 5.05. $C_{18}H_{15}Br$. Calculated %: C 69.46; H 4.85.

1,2,3,4-Tetrahydronaphthacene-6-carboxylic acid (VII). A benzene solution of 1 g 6-bromo-1,2,3,4-tetrahydronaphthacene (10 ml) was run into an ampoule containing n-butyllithium prepared from 0,62 g n-butyl chloride, 0,094 g lithium and 10 ml ether. After standing at room temperature for 30 minutes the reaction mass was poured onto solid carbon dioxide; when water was added a precipitate appeared at the boundary between the water and ether layers, consisting of 1,2,3,4-tetrahydronaphthacene (0.3 g). Acidification of the aqueous layer gave acid (VII) which was purified by reprecipitation from sodium carbonate solution, followed by recrystallization from glacial acetic acid. Yield 0.2 g (22.5% of acid with m.p. 195-196°)

4.296 mg substance: 12.972 mg CO_2; 2.390 mg H_2O. Found %: C 82.40; H 6.22. $C_{19}H_{16}O_2$. Calculated %: C 82.58; H 5.83.

6-Methyl-1,2,3,4-tetrahydronaphthacene (VIII). n-Butyllithium was prepared from 0,126 g lithium, 1.63 g n-butyl chloride and 10 ml ether. To the ethereal solution of n-butyllithium was added a benzene solution of 2 g 6-bromo-1,2,3,4-tetrahydronaphthacene (20 ml), whereupon the solution became considerably lighter in color. After standing for 30 minutes at room temperature, addition was made to the reaction mixture of 4.5 g methyl iodide diluted with 10 ml ether, and the mixture was again left at room temperature for an hour. The benzene-ether solution was washed with water and the solvents driven off. The yellow crystalline precipitate was crystallized from acetone to give 1.1 g (70%) of substance with m.p. 123-124.5°. After recrystallization from acetone, white needles were obtained with m.p. 127-128°. The hydrocarbon dissolves readily in carbon tetrachloride and chloroform, not so readily in acetone and ether.

4.110 mg substance: 13.951 mg CO_2; 2.763 mg H_2O. Found %: C 92.63; H 7.52. $C_{19}H_{18}$. Calculated %: C 92.63; H 7.36.

6,11-Dimethyl-1,2,3,4-tetrahydronaphthacene (IX). Into an ampoule containing a solution of n-butyllithium prepared from 0.05 g lithium and 0.3 g n-butyl chloride, was introduced 10 ml of a benzene solution of 0.7 g 6-methyl-11-bromo-1,2,3,4-tetrahydronaphthacene (m.p. 143-144°). The transparent brown reaction mixture was stood for an hour at room temperature. Addition of an ethereal solution of 1.2 g methyl iodide generated heat and the color changed to yellow. After standing for 40 minutes at room temperature, the ether-benzene solution was washed with water and the solvents distilled off. The yellow crystalline residue was crystallized from benzene-alcohol, giving 0.35 g 6,11-dimethyl-1,2,3,4-tetrahydronaphthacene with m.p. 139-142° (yield 62.5% of theory). After a second crystallization from benzene-alcohol the m.p. was 142-143.5°. 6,11-Dimethyl-1,2,3,4-tetrahydronaphthacene is readily soluble in benzene and chloroform and not so soluble in alcohol and acetone. It crystallizes from benzene in the form of elongated yellow platelets.

3.774 mg substance: 12.780 mg CO_2; 2.553 mg H_2O. Found %: C 92.41; H 7.57. $C_{20}H_{20}$. Calculated %: C 92.25; H 7.75.

The microanalyses were performed in our laboratory by assistant N. M. Krauze.

SUMMARY

1. n-Butyllithium or phenyllithium acts on 6,11-dibromo-, 6-methyl-11-bromo-, and 6-bromo-1,2,3,4-tetrahydronaphthacenes to form the corresponding organolithium compounds of 1,2,3,4-tetrahydronaphthacene.

2. A series of derivatives of 1,2,3,4-tetrahydronaphthacene was prepared with the help of organolithium compounds.

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* See Consultants Bureau translation, p. 203.

** See Consultants Bureau translation, p. 1659.

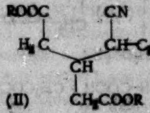
(Continued on inside back cover)

ISOQUINOLINE COMPOUNDS

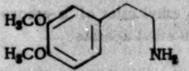
VI. SYNTHESIS OF γ-ETHYL-δ-VALEROLACTONE-β-ACETIC AND β-(α'-BROMOMETHO)-PROPYLGLUTARIC ACIDS

L. I. Zakharkin and N. A. Preobrazhensky

In carrying out our synthesis of the alkaloid emetine [1] (I) it was necessary to prepare a starting substance whose structure corresponded to the middle portion of the molecule of the alkaloid. For this purpose we have previously made successful use of an ester of β-(α'-cyano)-propylglutaric acid (II).


(II)

We found that the same objective is achieved satisfactorily by using γ-ethyl-δ-valerolactone-acetic acid (III) and the β-(α'-bromometho)-propylglutaric acid (IV) derived therefrom. Condensation of these compounds (III) and (IV) with homoveratrylamine (V), leads via a series of intermediate stages to emetine (I).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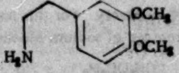
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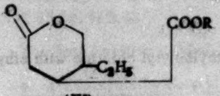
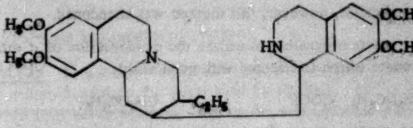
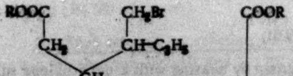
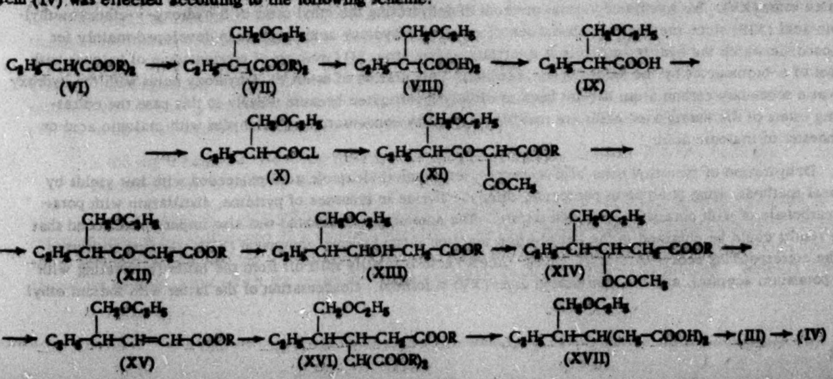

(III)


(I)


(IV)

The synthesis of γ-ethyl-δ-valerolactone-β-acetic acid (III) and of β-(α'-bromometho)-propylglutaric acid (IV) was effected according to the following scheme:



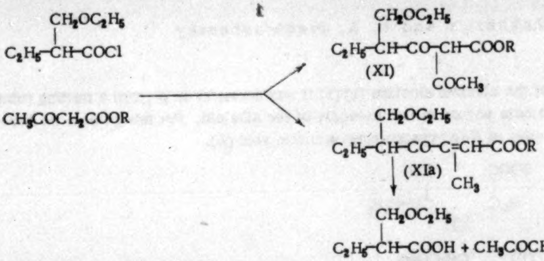
$$\underset{(VI)}{C_2H_5-CH(COOR)_2} \longrightarrow \underset{(VII)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{C}}-(COOR)_2} \longrightarrow \underset{(VIII)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{C}}-(COOH)_2} \longrightarrow \underset{(IX)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-COOH} \longrightarrow$$

$$\longrightarrow \underset{(X)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-COCl} \longrightarrow \underset{(XI)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-CO-\underset{COCH_3}{\underset{|}{CH}}-COOR} \longrightarrow$$

$$\longrightarrow \underset{(XII)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-CO-CH_2-COOR} \longrightarrow \underset{(XIII)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-CHOH-CH_2-COOR} \longrightarrow \underset{(XIV)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-\underset{OCOCH_3}{\underset{|}{CH}}-CH_2-COOR} \longrightarrow$$

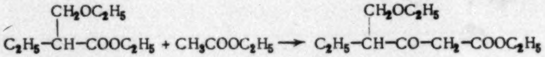
$$\longrightarrow \underset{(XV)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-CH{=}CH-COOR} \longrightarrow \underset{(XVI)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-\underset{CH(COOR)_2}{\underset{|}{CH}}-CH_2-COOR} \longrightarrow \underset{(XVII)}{C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{CH}}-CH(CH_2-COOH)_2} \rightarrow (III) \rightarrow (IV)$$

The ethyl ester of ethylmalonic acid (VI) is condensed with chloromethylethyl ether and the resultant ethoxymethylethylmalonic ester (VII) is saponified with alcoholic potash to give the dicarboxylic acid (VIII). Decarboxylation of the latter leads to α-ethoxymethylbutyric acid (IX). An interesting feature is the simultaneous formation of ethacrylic acid. The acid chloride (X) is condensed with sodium ethylacetoacetate and from the resultant mixture of isomeric acyl derivatives (XI) and (XIa) the ethyl ester of α-aceto-β-keto-γ-ethoxymethylcaproic acid (XI) is isolated by extraction with cold dilute potassium hydroxide solution. Saponification of the acyl derivative (XIa) with sodium hydroxide gives the original γ-ethoxymethylbutyric acid:



Treatment of compound (XI) with dry ammonia in ether solution yields the ester of β-keto-γ-ethoxymethylcaproic acid (XII).

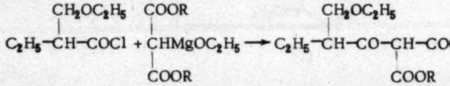
Other routes to the ethyl ester of β-keto-γ-ethoxymethylcaproic acid were also investigated, avoiding the step of condensation of α-ethoxymethylbutyryl chloride with sodium ethylacetoacetate since the yield of the required acyl derivative (XI) does not exceed 50% of theory. For this purpose the ethyl ester of α-ethoxymethylbutyric acid was prepared and condensed in presence of sodium alcoholate with ethyl acetate:



$$C_2H_5-\underset{}{\overset{CH_2OC_2H_5}{\overset{|}{C}H}}-COOC_2H_5 + CH_3COOC_2H_5 \longrightarrow C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{C}H}-CO-CH_2-COOC_2H_5$$

In view of the poor yields, however, this method was abandoned.

Similarly it was impossible to utilize the condensation of α-ethoxymethylbutyryl chloride with ethyl magnesium malonate which is effected with good yield:



$$C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{C}H}-COCl + \underset{\underset{COOR}{|}}{\overset{\overset{COOR}{|}}{C}}HMgOC_2H_5 \longrightarrow C_2H_5-\overset{CH_2OC_2H_5}{\overset{|}{C}H}-CO-\underset{\underset{COOR}{|}}{C}H-COOR \quad \text{(XVIII)}$$

because difficulties arise in the subsequent cleavage of the α-carboxy group by heating with a naphthalene sulfonic acid [2].

The compound (XII) is converted into the sought for substance by the following steps: The ethyl ester (XII) is catalytically reduced to the corresponding hydroxy derivative (XIII) which is then dehydrated to the unsaturated ester (XV). We examined various methods of dehydrating the ethyl ester of β-hydroxy-γ-ethoxymethylcaproic acid (XIII) since methods of dehydration of esters of β-hydroxy acids have been developed mainly for compounds in which the hydroxy group is at a tertiary carbon atom [3] (products of condensation of ketones with an ester of α-bromoacids by the Reformatsky reaction). Dehydration of esters of β-hydroxy acids with the hydroxy group at a secondary carbon atom has not been so closely investigated because usually in this case the corresponding esters of the unsaturated acids are readily prepared by condensation of aldehydes with malonic acid or a monoester of malonic acid.

Dehydration of the ethyl ester of β-hydroxy-γ-ethoxymethylcaproic acid proceeded with low yields by the usual methods, using phosphorus pentoxide, thionyl chloride in presence of pyridine, distillation with potassium carbonate or with potassium hydrogen sulfate. The unsaturated compound was also impure. We found that better results could be obtained in the dehydration reaction if the hydroxy compound (XIII) was first converted into the corresponding acetyl derivative (XIV). Acetic acid is readily split off from the latter (by heating with fused potassium acetate), and the unsaturated ester (XV) is formed. Condensation of the latter with sodium ethyl malonate gives the tricarboxylic acid ester (XVI) which is converted by saponification and decarboxylation into β-(α'-ethoxymethopropylglutaric acid (XVII). Heating of the latter with 48% hydrobromic acid gives γ-ethyl-δ-valerolactone-β-acetic acid (III) which we isolated in both a liquid and a crystalline form. Both these forms react with dry hydrogen bromide to form β-(α'-brommetho)-propylglutaric acid.

EXPERIMENTAL

1. Diethyl ester of ethoxymethylethylmalonic acid (VII). To 12 g finely divided sodium under 200 ml dry benzene is added 1 ml absolute alcohol and then, gradually, 94 g ethylmalonic ester. After the sodium had dissolved, the reaction mass is cooled and gradual addition made with energetic stirring of 50 g chlormethylethyl ether at such a rate that the temperature does not rise above +2°. The stirrer is then stopped and the mass allowed to stand overnight. On the following day the mixture is heated with stirring at 60-65° for 20 minutes. After cooling, water is added to dissolve the sodium chloride and the benzene layer is separated and washed with soda solution. The benzene is distilled off in vacuum. The diethyl ester of ethoxymethylethylmalonic acid has b.p. 114-117° at 9 mm. Yield 94 g or 76.5% of the theoretical.

2. Ethoxymethylethylmalonic acid (VIII). To a solution of 75 g potassium hydroxide in 300 ml methyl alcohol is added 111 g diethyl ester of ethoxymethylethylmalonic acid and the mixture agitated until the latter dissolves. The solution is stood overnight and on the next day it is heated on the water bath to the boiling point of the alcohol for two hours. Addition is then made of 150 ml water to dissolve the potassium salt and the methyl alcohol is taken off in vacuum. The residual transparent aqueous solution is acidified with concentrated hydrochloric acid and extracted several times with ether. After removing the solvent, the residue crystallizes. Yield 83 g (97.5%). M.p. 69-70° after recrystallization from benzene-ligroin.

3.010 mg substance: 5.570 mg CO_2; 1.950 mg H_2O. Found %: C 50.50; H 7.25. $C_8H_{14}O_5$.
Calculated %: C 50.50; H 7.42.

3. α-Ethoxymethylbutyric acid (IX). 80 g of ethoxymethylethylmalonic acid is heated on an oil bath at 155-160° for 40 minutes until carbon dioxide ceases to come off. The product is then fractionated in vacuum. B.p. 113-115° at 9 mm. Yield 42.5 g (69 % of theory); n_D^{10} 1.4278.

2.995 mg substance: 6.305 mg CO_2; 2.605 mg H_2O. Found %: C 57.45; H 9.73. $C_7H_{14}O_3$. Calculated %: C 57.50; H 9.65.

The first fraction yielded 10 g α-ethacrylic acid with b.p. 178-180°.

4. α-Ethoxymethylbutyryl chloride (X). 45 g α-ethoxymethylbutyric acid is mixed with 50 g thionyl chloride and left overnight. The mixture is then heated on the water bath for an hour. The excess of thionyl chloride is distilled off and the acid chloride distilled in vacuum. B.p. of the acid chloride 57-58° at 8 mm. Yield 47 g (92.5% of theory).

5. Ethyl ester of α-carbethoxy-β-oxo-γ-ethoxymethylcaproic acid (XVIII). To 2.5 g magnesium turnings, 2.5 ml absolute alcohol, and 0.1 ml carbon tetrachloride is gradually added a mixture of 16 g ethyl malonate and 3 ml absolute alcohol. The reaction of formation of the magnesium compounds proceeds energetically and cooling is necessary at the start. After the reaction has slowed down, addition is made to the flask of 30 ml dry ether, and the flask is heated on the water bath until the whole of the magnesium has dissolved. Slow addition is then made to the ethyl magnesium malonate of a solution of 17 g α-ethoxymethylbutyryl chloride in 20 ml dry ether at such a speed that the ether boils. After all has been added, the transparent ethereal solution is heated on the water bath for an hour. After cooling with ice water, addition is made to the reaction mass of 30 ml water and then of dilute hydrochloric acid in amount necessary to dissolve the magnesium compounds. The ethereal solution is washed once with water and dried with sodium sulfate. The residue (after removal of solvent) is distilled in vacuum. B.p. 143-145° at 6 mm. Yield 21 g (73 %). A dark-red solution is formed with an alcoholic solution of iron chloride: n_D^{20} 1.4511.

3.465 mg substance: 7.435 mg CO_2; 2.635 mg H_2O. Found %: C 58.55; H 8.51. $C_{14}H_{24}O_6$.
Calculated %: C 58.30; H 8.39.

6. Ethyl ester of α-aceto-β-keto-γ-ethoxymethylcaproic acid (XI). Sodium ethylacetoacetate is prepared from 4.8 g sodium and 28 g ethylacetoacetate in 150 ml absolute ether. Gradual addition is made to it, with stirring and cooling to −6 to 3°, of 33 g α-ethoxymethylbutyryl chloride. Stirring is then continued for an hour, after which the reaction mass is heated on the water bath for 30 minutes. Water is added

to dissolve the sodium chloride. The ether solution is washed once with water and dried with calcined sodium sulfate. The ether is distilled off on the water bath and the residue cooled with ice-salt mixture and extracted with cold 7% potassium hydroxide solution until the whole of the acyl derivative has been extracted. The alkaline solution is extracted once with ether and the cooled residue is acidified with dilute hydrochloric acid. The separated oil is extracted with ether and the ether extract washed several times with bicarbonate solution. After drying with sodium sulfate, the ether is distilled off and the residue distilled in vacuum. B.p. 130-132° at 9 mm. Yield 24.2 g (46.5% of theory); n_D^{20} 1.4691.

3.000 mg substance; 6.665 mg CO_2; 2.340 mg H_2O. Found %: C 60.54; H 8.73. $C_{13}H_{22}O_5$.
Calculated %: C 60.43; H 8.59.

7. Ethyl ester of β-keto-γ-ethoxymethylcaproic acid (XII). 38 g ethyl ester of α-aceto-β-keto-γ-ethoxymethylcaproic acid is dissolved in 60 ml dry ether. A stream of dry ammonia is passed through the solution (cooled to 0°). After complete saturation with ammonia, the solution is left overnight. Water is then added to dissolve the precipitated acetamide. The ether solution is washed with dilute hydrochloric acid and water. After drying with sodium sulfate, the ether is distilled off and the residue distilled in vacuum. B.p. 115-117° at 8 mm. Yield 27 g (83.5% of theory); n_D^{20} 1.4395.

3.450 mg substance; 7.740 mg CO_2; 2.790 mg H_2O. Found %: C 61.22; H 9.05. $C_{11}H_{20}O_4$.
Calculated %: C 61.07; H 9.33.

8. Ethyl ester of β-hydroxy-γ-ethoxymethylcaproic acid (XIII). 27 g ethyl ester of β-keto-γ-ethoxymethylcaproic acid, 30 ml absolute alchol and 6 g nickel catalyst are charged into an autoclave and hydrogenation is carried out at 125-130° and 150-160 atm for two hours. The alcoholic solution is freed from catalyst, the alcohol distilled off on the water bath and the residue distilled in vacuum. B.p. 120-121° at 8 mm. Yield 26 g (95.3%); n_D^{20} 1.4395.

2.995 mg substance: 6.545 mg CO_2; 2.730 mg H_2O. Found %: C 60.44; H 10.34. $C_{11}H_{22}O_4$.
Calculated %: C 60.50; H 10.16.

9. Ethyl ester of β-acetoxy-γ-ethoxymethylcaproic acid (XIV). 26 g ethyl ester of β-hydroxy-γ-ethoxymethylcaproic acid is heated on the oil bath with 39 ml acetic anhydride for an hour. The acetic acid and excess of acetic anhydride are removed in vacuum. B.p. 131-133° at 9 mm. Yield 30.2 g (97.4% of theory); n_D^{20} 1.4337.

3.064 mg substance: 6.760 mg CO_2; 2.500 mg H_2O. Found %: C 60.19; H 9.13. $C_{13}H_{24}O_5$.
Calculated %: C 59.96; H 9.30.

10. Ethyl ester of γ-ethyl-γ-ethoxymethylcrotonic acid (XV). 30.2 g ethyl ester of β-acetoxy-γ-ethoxymethylcaproic acid and 1.5 g fused potassium acetate are heated on a gauze. Acetic acid distils off (the temperature must not exceed 150-155°). When this stage is completed, the mass is cooled and water is added to dissolve the potassium acetate. The oil is extracted with ether. From the distillate, after neutralization, is obtained another crop of substance. The ethereal solution is washed with sodium bicarbonate solution and with water. After drying with sodium sulfate, the ether is driven off and the residue distilled in vacuum. B.p. 103-106° at 9 mm. Yield 20.1 g (86.5%); n_D^{20} 1.4465.

3.095 mg substance:. 7.510 mg CO_2; 2.785 mg H_2O. Found %: C 66.22; H 10.07. $C_{11}H_{20}O_3$. Calculated %: C 65.95; H 10.07.

11. Diethyl ester of α-carbethoxy-β-(α'-ethoxymetho)-propylglutaric acid (XVI). 2.3 g sodium is dissolved in 40 ml absolute alcohol and after cooling addition is made of 32 g ethyl malonate. The mixture is heated to the boil on the water bath and addition is gradually made of 20 g ethyl ester of γ-ethyl-γ-ethoxymethylcrotonic acid. The solution is heated on the water bath for 6 hours, after which the alcohol is removed in vacuum. The residue is cooled, addition is made of 70 ml benzene and of dilute hydrochloric acid until the reaction is acid to congo. The benzene solution is separated from the aqueous layer and washed several times with sodium bicarbonate solution until the aqueous extracts are colorless. The benzene is removed in vacuum. B.p. 146-148° at 2 mm. Yield 28.5 g (79% of the theoretical); n_D^{20} 1.4519.

3.000 mg substance: 6.600 mg CO_2; 2.310 mg H_2O. Found %: C 60.04; H 8.62.
$C_{18}H_{32}O_7$. Calculated %: C 59.96; H 8.95.

12. β-(α'-Ethoxymetho)-propylglutaric acid (XVII). To a solution of 12.6 g potassium hydroxide in

80 ml water and 160 ml methyl alcohol is added 27 g diethyl ester of β-carbethoxy-β-(α'-ethoxymetho)-propylglutaric acid. The mixture is heated on the water bath for three hours. Water is then added and the methyl alcohol distilled off in vacuum. The aqueous solution is acidified with concentrated hydrochloric acid and extracted several times with ether. The ether is removed on the water bath and the residue heated on an oil bath at 155-160° for 40 minutes until carbon dioxide ceases to come off. There is obtained 16.5 g (95%) of β-(α'-ethoxymetho)-propylglutaric acid with m.p. 190-194° at 3 mm. The acid is a colorless, viscous oil.

2.945 mg substance: 6.150 mg CO_2; 2.240 mg H_2O. Found %: C 56.99; H 8.51. $C_{11}H_{20}O_5$. Calculated %: C 56.86; H 8.68.

13. γ-Ethyl-δ-valerolactone-β-acetic acid (III). 25 g β-(α'-ethoxymetho)-propylglutaric acid is dissolved in 250 g 48% hydrobromic acid and the solution heated at the boil for 6 hours. The hydrobromic acid is then driven off by heating on a water bath in vacuum. To the viscous residue is added 50 ml water and the solution extracted several times with ether. The ether is distilled off and the residue distilled in vacuum. B.p. 170-173° at 3 mm. Yield 16.3 g (81.5%). After standing for a short period the oily product crystallizes, giving 5.65 crystalline acid. Both these substances are lactones of one and the same composition, judging by the analytical and titration data. The melting point of crystalline γ-ethyl-δ-valerolactone-β-acetic acid after recrystallization from benzene is 102.5-103.5°.

a) Crystalline acid. 3.000 mg substance: 6.410 mg CO_2; 1.955 mg H_2O. Found %: C 58.31; H 7.29. $C_9H_{14}O_4$. Calculated %: C 58.03; H 7.58.

Neutralization of 0.2012 g substance in the cold required 12.2 ml 0.0891 N NaOH; after boiling with excess alkali the consumption was 24.3 ml 0.0891 N NaOH. Found: M 185, 92.7. $C_9H_{14}O_4$. Calculated: M 186, 93.0.

b) Liquid acid. 3.600 mg substance: 7.655 mg CO_2; 2.375 mg H_2O. Found %: C 58.03; H 7.38. $C_9H_{14}O_4$. Calculated %: C 58.03; H 7.58.

Neutralization of 0.1436 g substance in the cold consumed 8.7 mg 0.0891 N NaOH; after boiling with excess alkali the consumption was 17.4 ml 0.0891 N NaOH. Found: M 185.5, 92.7. $C_9H_{14}O_4$. Calculated: M 186.0, 93.0.

14. β-(α'-Bromometho)-propylglutaric acid (IV). A solution of 5 g γ-ethyl-δ-valerolactone-β-acetic acid in 50 ml glacial acetic acid is saturated with dry hydrogen bromide at 0° and left for 48 hours. The acetic acid is then distilled off in vacuum at 40° on the water bath. The residue is dissolved in benzene and the benzene distilled off in vacuum. A small quantity of ether is added; after a short period the mass thickens due to separation of crystals. The crystals are collected on a filter and washed with a little benzene. Yield 3.2 g (44.6%). M.p. 132.5-133.5° after recrystallization from benzene.

2.835 mg substance: 4.220 mg CO_2; 1.455 mg H_2O. Found %: C 40.62; H 5.74. $C_9H_{15}O_4Br$. Calculated %: C 40.44; H 5.66.

SUMMARY

A method is developed for the preparation of γ-ethyl-δ-valerolactone-β-acetic acid and the ester of β-(α'-bromometho)-propylglutaric acid, starting materials for the synthesis of emetine.

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Fine Chemical Technology

PREPARATION OF 3,4-DIMETHYLPHENYL-*d*-RIBAMINE

BY THE REARRANGEMENT METHOD

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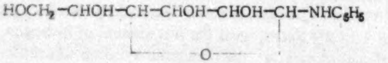
3,4-Dimethylphenyl-*d*-ribamine is an intermediate in the synthesis of vitamin B_2, riboflavin. It can be easily prepared by condensation of 3,4-dimethylaniline with *d*-ribose. But *d*-ribose is not a readily accessible substance, so that great interest has developed in methods of synthesis of this interemediate from more accessible starting products, in particular from *d*-arabinose.

The structure of the glucosoanilides has been discussed ever since their discovery [1,2,3]. Sorokin and Marshevsky [4] investigated the hexose anilides and ascribed to the reaction products a glucoside structure characterized by a γ-bond:



$HOCH_2-CHOH-CH-CHOH-CHOH-CH-NHC_6H_5$

Schiff [5] and Straus [6] favored the aminoaldehyde formula. They claimed that reaction of a sugar with an amine leads to Schiff bases $-HOCH_2-(CHOH)_4-CH{=}NC_6H_5$. Irvine and co-workers [7] inclined to the N-glucoside formula.

Arylamino-N-glucosides are prepared by heating a sugar with an amine without a solvent or with a solvent (alcohol, water, benzene). Partial removal of the solvent causes the N-glucosides to crystallize. A catalyst was needed for the formation of some N-glucosides (NH_4Cl, HCl, etc.) [8].

The majority of the N-glucosides remain unchanged only in the absolutely pure state. Marked changes are caused by the presence of traces of impurities.

Amadori [9] showed that fusion, and also prolonged digestion, of amines with sugars leads to formation, not of N-glucosides, but of their isomers. Kuhn and Wygand [10] obtained *p*-tolyl-*d*-isoglucosamine from *p*-toluidine and *d*-glucose.

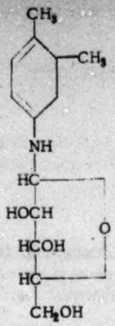
Following a detailed study of the conditions of rearrangement for derivatives of hexoses, the possibility of rearrangement of N-pentosides was investigated.

Of particular interest in connection with the synthesis of vitamin B_2 is the coupling of *d*-arabinose with 3,4-dimethylaniline, since their interaction followed by rearrangement and hydrogenation gives 3,4-dimethylphenyl-*d*-ribamine. Condensation of 3,4-dimethylaniline with *d*-arabinose leads to formation of 3,4-dimethylphenyl-*d*-arabinoside (I), which, when heated in an acid medium, rearranges to 3,4-dimethylphenyl-*d*-isoarabinosamine (II); reduction of the latter by hydrogen in presence of platinum in a weakly alkaline medium gives 3,4-dimethylphenyl-*d*-ribamine (III). During the reaction *d*-isoarabinosamine was not isolated in the free state. Berezovsky, Kurdyukova and Preobrazhensky [12], using a platinum catalyst, prepared *d*-ribosamine from *d*-arabinose in a yield of about 13 % of the theoretical. (For diagram see next page)

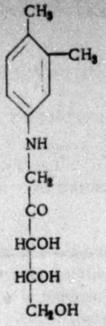
The present investigation was undertaken because of the need to raise the yield of *d*-ribamine and to replace the platinum catalyst by the cheaper nickel catalyst. In the investigation, attempts were made to perform the rearrangement in various conditions and also to carry out the hydrogenation with nickel catalyst.

EXPERIMENTAL

The condensation of the sugar with the amine and the rearrangement were carried out in a round-bottomed flask. The subsequent hydrogenation was performed in a pear-shaped glass vessel with a fused-on glass tube bent at a right-angle.



(I)



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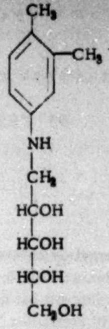

(III)

Energetic stirring was applied. The reaction temperature ranged from 80 to 95°.

5 g d-arabinose, 4 g 3,4-dimethylaniline and 0.25 g benzoic acid were heated on the water bath. The reaction period varied from 5 to 10 minutes. The dark solution was hydrogenated in presence of platinum in an alcoholic alkaline medium (using 2 ml 2N NaOH) until the full amount of hydrogen was absorbed. After completion of hydrogenation and removal of catalyst, the unreacted xylidine was removed by steam distillation. The aqueous solution in the distilling flask was concentrated to a small volume. The precipitate of d-ribamine was crystallized from butyl alcohol. M.p. 141-142°. Yield 1.0 to 1.3 g d-ribamine (12-14%). $[\alpha]_D^{18}$ + + 10° (using pyridine as solvent).

Isolation of 3,4-dimethylphenyl-d-arabinoside. 10 g d-arabinose, 8 g 3,4-dimethylaniline and 80 ml ethyl alcohol were heated to the boil under a reflux condenser for about an hour. Cooling resulted in separation from the filtrate of white crystals of the d-arabinoside with m.p. 125-126° (yield about 95-98%). The identity of the d-arabinoside was confirmed by preparation of d-arabinamine by hydrogenation in presence of platinum. M.p. 139-141° $[\alpha]_D^{18}$ + 10° (in pyridine).

Rearrangement of 3,4-dimethylphenyl-d-arabinoside. Attempts to isolate d-isoarabinosamine in the free state by rearrangement of the prepared d-arabinoside in a weakly acid medium at various pH values were unsuccessful. In all cases resinous bodies were obtained in which the presence of isoarabinosamine could only be detected qualitatively (reaction with 2,6-dichlorphenol-indophenol *). Small amounts of d-ribamine were isolated by hydrogenation of the resin.

Experiments on the rearrangement of d-arabinoside into d-isoarabinosamine in an alcoholic-acid medium under a hydrogen pressure of 100 atmospheres at 25-30° did not meet with success. Rearrangement of d-arabinoside in an alcoholic-acid medium in an autoclave under a hydrogen pressure of 50 atmospheres at 80-85° for 3 hours, followed by hydrogenation with nickel catalyst in a weakly alkaline medium, led in all cases to a mixture of d-ribamine and d-arabinamine, as was confirmed by the melting point and the specific rotation.

8 g d-arabinoside, 0.4 g benzoic acid and 25 ml 95% ethyl alcohol were heated in a rotating autoclave at 80-85° for 3 hours under a hydrogen pressure of 50 atmospheres. After cooling, addition was made to the autoclave of 25-30 ml ethyl alcohol (95%), 3-5 g nickel catalyst and 3 ml 2N NaOH. Hydrogenation was carried out for 6 hours at 60-65° with a hydrogen pressure of 25 atmospheres. A substance with m.p. 124-125° was isolated in a yield of 15-17% of the theoretical. $[\alpha]_D^{18}$ −13°.

Hydrogenation in a weakly acid medium. 10 g d-arabinose, 8 g 3,4-dimethylaniline, 0.4 g benzoic acid and 40 ml 95% alcohol were heated in a rotating autoclave at 80-85° under a hydrogen pressure of 50 atmospheres for an hour. Into the autoclave, after cooling, were introduced 5-6 g nickel catalyst and 30 ml alcohol. Hydrogenation was performed without addition of alkali in a weakly acid medium for 4 hours at 50-60° under a hydrogen pressure of 25 atmospheres.

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* Isosaccharoamines possess the property of reducing certain dyes in the cold: for instance, methylene blue and 2,6-dichlorphenol-indophenol. On the other hand glucosides do not exhibit this property.

A compound with m.p. 134-135° was isolated in 35-40% yield. After recrystallization from butyl alcohol the m.p. was 138-139°; $[\alpha]_D^{18}$ −11° (in pyridine).

From the saccharoamine prepared by the last method was prepared an azo compound; this was condensed with barbituric acid to give a flavin dye [13] with m.p. 272° which rose to 290° after recrystallization (pure riboflavin melts at 290°, araboflavin at 302°).

Biological tests with the flavin dye on rats showed the activity to be half that of riboflavin (vitamin B_2). This once again confirms the possibility of contamination of the prepared product with arabinamine. Thus the araboflavin formed during the synthesis of the dye lowers the biological activity.

SUMMARY

1. 3,4-Dimethylphenyl-d-arabinoside was isolated in a yield of about 95-98% of the theoretical.

2. It was impossible to prepared 3,4-dimethylphenyl-d-isoarabinosamine in the free state by rearrangement of d-arabinoside at various pH values.

3. d-Arabinoside does not rearrange to d-isoarabinosamine under a hydrogen pressure of 100 atmospheres at 25-30°.

4. Rearrangement of d-arabinoside in an alcoholic acid medium in an autoclave under a hydrogen pressure of 50 atmospheres at 80-85° followed by hydrogenation with nickel catalyst in an alcoholic alkaline medium leads to a mixture of d-ribamine and d-arabinamine in a yield of 15-17% of the theoretical.

5. Rearrangement in an autoclave under pressure followed by hydrogenation with nickel catalyst in a weakly acid medium leads to a product consisting of d-ribamine and d-arabinamine in a yield of about 35-40% of the theoretical.

6. The synthesized flavin dye proved to possess one-half of the biological activity of riboflavin (vitamin B_2).

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THE ALKAOIDS OF GALANTHUS WORONOWI

II. ISOLATION OF A NEW ALKALOID

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In the preceding paper on the alkaloids of Galanthus Woronowi Amaryllidaceae family) one of us reported the isolation from the bulbs of this plant of two new alkaloids named galantine and galantidine. In the examination of the mother liquors after separation of these two alkaloids, we succeeded in isolating a third alkaloid which proved to be a base not previously described in the literature; we have named it galantamine.

The elementary analysis of galantamine leads to the formula $C_{17}H_{21}O_3N$. Galantamine is a fairly strong monoacidic base with m.p. 126-127° and a specific rotation of $[\alpha]_D -118.8°$. It is very readily soluble in alcohol, acetone and chloroform; less easily soluble in benzene and ether; it is fairly soluble in hot water. It forms a series of well-crystallized salts: hydrochloride, m.p. 256-257°; hydrobromide, m.p. 246-247°; perchlorate, m.p. 223-224°; nitrate, m.p. 224-225°; chloroplatinate, m.p. 216-217°; all of these, like the base, are levorotary.

Galantamine contains a nonphenolic hydroxyl group, a methoxyl and a methylimino group. The third oxygen atom is in a reactive-inactive form. Consequently the formula of galantamine may be represented as $C_{15}H_{14}(NCH_3)(OCH_3)(OH)O$.

The presence of a hydroxyl group in galantamine was confirmed by the preparation of a monoacetyl derivative $C_{17}H_{20}O_3N(CH_3CO)$; m.p. 129-130°

The molecule of galantamine contains one double bond which is rather difficult to hydrogenate both with platinum catalyst (Adams) and with Raney nickel. Analysis of the hydrogenation product, m.p. 116-118°, corresponds to the formula $C_{17}H_{23}O_3N$. The melting points of dihydrogalantamine and of most of its derivatives are very close to those of galantamine and its corresponding derivatives, and the mixed samples for the most part do not exhibit any depression of melting point. However, the properties of dihydrogalantamine perchlorate and of such derivatives as the hydrobromide of the acetyl derivative and the perchlorate of the product of decomposition of dihydrogalantamine provided conclusive evidence of the presence of a hydrogenatable double bond in galantamine.

Methylation of glantamine with methyl iodide yielded a crystalline methyl iodide addition product with m.p. 278-279°; $[\alpha]_D -94.5°$. Galantamine-methyl iodide very readily decomposes when heated with 25% alcoholic potassium hydroxide and forms a product with m.p. 80-82° whose elementary analysis corresponds to $C_{18}H_{23}O_3N$. The following salts were prepared to characterize the decomposition product: perchlorate, m.p. 221.5°-222.5°; picrate, m.p. 148-151°; methyl iodide compound, m.p. 188-189°.

EXPERIMENTAL

Extraction of the alkaloids. 25 kg dried and powdered bulbs of the Caucasian wild snowdrop are moistened with 7% ammonia solution and extracted with dichlorethane until the alkaloids are completely removed. The dichlorethane extract is extracted with 10% sulfuric acid. The sulfuric acid solution of the alkaloids is washed with ether to remove traces of dichlorethane and then made alkaline with ammonia.

Isolation of galantine and galantidine. After standing for a short period, the alkaline solution deposits a crystalline precipitate of galantine and galantidine (80.8 g) which is filtered at the pump and washed with water.

Separation of galantamine. The alkaline mother liquor, after separation of the crystalline alkaloids, is extracted with ether. The ether is distilled off to leave a yellow, viscous mass (58 g), from which by treatment with 10% hydrobromic acid solution, is deposited the crystalline hydrobromides of galantine and galantamine. The mixture of hydrobromides is washed and then digested with alcohol. The hydrobromide of galantine goes into solution in the alcohol while galantamine hydrobromide remains undissolved. Yield 22 g, m.p. 234-235°.

Recrystallization from water gives 20 g of galantamine hydrobromide with m.p. 246-247°.

3.315 mg substance: 6.786 mg CO_2; 2.021 mg H_2O. 3.439 mg substance: 6.994 mg CO_2; 2.021 mg H_2O. 3.322 mg substance: 1.753 mg AgBr. 3.267 mg substance: 1.713 mg AgBr. Found %: C 55.47, 55.65; H 6.59, 6.81; N 4.07, 3.8; Br 22.45, 22.31. $C_{17}H_{21}O_3N \cdot HBr$. Calculated %: C 55.45; H 5.98; N 3.8; Br 21.79. 0.1015 g substance in 15 ml water; $\underline{1}$ 1 dcm; α_D −0.63°; $[\alpha]_D$ −93.1°.

Separation of the base. 20 g galantamine hydrobromide (m.p. 246-247°) is dissolved in 15 ml water, made alkaline with ammonia and extracted with ether. Removal of the ether leaves 16 g light-yellow oil which soon crystallizes. The fine crystalline precipitate obtained by trituration with acetone is filtered at the pump and washed with acetone. Yield 12.8 g galantamine with m.p. 117-119°. After recrystallization from water or benzene the m.p. is 126-127°. 3.246 mg substance: 8.488 mg CO_2; 2.159 mg H_2O. 2.929 mg substance: 7.721 mg CO_2; 2.034 mg H_2O. 18.980 mg substance: 1.35 ml CH_4. 10.726 mg substance: 0.82 ml CH_4. Found %: C 71.32, 71.88; H 7.45, 7.65; N 4.93, 4.76; OH 4.98, 5.28. $C_{17}H_{21}O_3N$. Calculated %: C 71.08; H 7.315; N 4.87; OH 4.88.

0.1378 g substance in 10 ml alcohol; $\underline{1}$ 1 dcm; α_D −1.637°; $[\alpha]_D$ −118.8°.

Preparation of the salts. Galantamine nitrate. To 0.2 g galantamine with m.p. 126-127° is added 10% nitric acid solution until weakly acid. Rubbing with alcohol yields a finely crystalline precipitate of galantamine nitrate in amount of 0.2 g with m.p. 221-222.5°. Recrystallization from 3 ml alcohol gave 0.15 g with m.p. 224-225°.

3.267 mg substance: 6.847 mg CO_2; 1.785 mg H_2O. Found %: C 57.16; H 6.12. $C_{17}H_{21}O_3N \cdot HNO_3$. Calculated %: C 58.3; H 6.28.

Perchlorate. To a solution of 0.1 g galantamine in 1 ml 10% acetic acid is added a solution of the calculated amount of sodium perchlorate. After traces of acetic acid have been removed, by rubbing with alcohol a colorless finely crystalline precipitate is obtained; this is washed with alcohol, and dried in a vacuum desiccator. Galantamine perchlorate melts at 223-224°.

Hydrochloride. Addition is made to galantamine of 5% hydrochloric acid solution until the reaction is weakly acid. The precipitate of hydrochloride is purified by crystallization from water; m.p. 256-257°.

Galantamine hydrochloride is very sparingly soluble in alcohol; it is quite insoluble in acetone; it dissolved with difficulty in cold water, more readily in hot.

Chloroplatinate. 0.1 g galantamine is dissolved in 1% hydrochloric acid, and to the solution is added dropwise a solution of platinum chloride. Fine yellow crystals of galantamine chlorplatinate are precipitated. After recrystallization from water the m.p. is 216-217°. The salt is very sparingly soluble in alcohol and rather more soluble in water.

Methyl iodide addition product. To a solution of 3 g galantamine in 60 ml acetone is added 6 ml methyl iodide; a white crystalline precipitate of galantamine-methyl iodide at once comes down. The reaction is completed by heating the mixture for 30 minutes. After cooling, the precipitate is filtered at the pump and washed with acetone. Yield 4.3 g methyl iodide with m.p. 254-255°.

After two recrystallizations from alcohol-water the methyl iodide addition product has m.p. 279°.

4.764 mg substance: 6.63 ml 0.01 N. $Na_2S_2O_3$. 5.320 mg substance: 7.40 ml 0.01 N $Na_2S_2O_3$. Found %: I 29.49, 29.46. $C_{17}H_{21}O_3N \cdot CH_3I$. Calculated %: I 29.6.

0.1002 g substance in 15 ml water; $\underline{1}$ 1 dcm; α_D −0.63°; $[\alpha]_D$ −94.5°.

Action of acetic anhydride on galantamine. 0.2 g galantamine is mixed with 2.5 ml pyridine and 2.5 ml acetic anhydride and the mixture heated on the water bath at 25-35°. After 5-10 minutes the precipitate goes into solution. Heating is continued for 12 hours. After vacuum distillation of the pyridine and excess of acetic anhydride, a 10% hydrobromic acid solution is added until the reaction is weakly acid. Treatment with acetone brings down white crystals of acetylgalantamine hydrobromide.

After three recrystallizations from alcohol-water the hydrobromide is in the form of beautiful large needles with m.p. 246-247°.

Acetylgalantamine is almost insoluble in alcohol and acetone, very soluble in water; a mixture with galantamine hydrobromide has a depressed melting point of 242-244°. The acetylgalantamine base isolated from the hydrobromide melts at 129-130°; like the hydrobromide, it depresses the melting point of galantamine; the mixture melts at 94-96°.

3.482 mg substance: 8.809 mg CO_2; 2.139 mg H_2O. Found %: C 69.19; H 6.87. $C_{17}H_{20}O_3N(CH_3CO)$. Calculated %: C 69.30; H 6.99.

Action of alcoholic KOH on galantamine-methyl iodide. 3 g of galantamine-methyl iodide is mixed with 30 ml 25% potassium hydroxide solution in methyl alcohol and heated on the water bath for 45 minutes. On cooling, the reaction mixture is diluted with ether and separated from the alkaline solution; the ethereal solution is washed with 8 ml water to remove the alcohol and alkali, dried and distilled. The residue (2.06 g) after removal of the ether is a semiliquid, partly crystallizing oil which is triturated with ether. The precipitated crystals are filtered at the pump and washed with ether.

After recrystallization from petroleum ether there is obtained 1.44 g des-N-methylgalantamine with m.p. 80-82°.

3.485 mg substance: 9.209 mg CO_2; 2.291 mg H_2O. 3.172 mg substance: 8.370 mg CO_2; 2.060 mg H_2O. 6.350 mg substance: 0.276 ml N_2 (19.0°, 736.5 mm). 6.744 mg substance: 0.284 ml N_2 (21.0°, 728.6 mm). 9.834 mg substance: 0.77 ml CH_4. 10.916 mg substance: 0.85 ml CH_4. 7.887 mg substance: 7.70 ml $Na_2S_2O_3$ (0.02 N); 8.95 ml $Na_2S_2O_3$ (0.02 N). Found %: C 72.06, 71.96; H 7.35, 7.26; N 4.92, 4.69; OH 5.47, 5.44; OCH_3 10.09; NCH_3 10.98. $C_{18}H_{21}O_3N$. Calculated %: C 72.2; H 7.0; N 4.7; OH 5.6; OCH_3 10.23; NCH_3 9.57.

Picrate of des-N-methylgalantamine. Addition of picric acid solution to an aqueous solution of des-N-methylgalantamine leads to separation of a resin from which the aqueous mother liquor is decanted. Treatment of the resin with alcohol results in formation of a powdery precipitate. It is filtered at the pump and washed. The picrate melts at 148-151°.

Perchlorate. To 0.1 g des-N-methylgalantamine is added 5% hydrochloric acid solution until the reaction is weakly acid and a solution of 0.1 g sodium perchlorate. A turbidity appears, followed by a finely crystalline precipitate. After recrystallization from water 0.07 g perchlorate was obtained with m.p. 221.5-222.5°.

Methyl iodide addition product. 0.6 g des-N-methylgalantamine is dissolved in 30 ml acetone; 1.5 g methyl iodide is then added and the mixture heated for 30 minutes. After concentration to a small volume a crystalline precipitate of the methyl iodide is obtained and is twice recrystallized from alcohol to form rhombic plates (0.62 g) with m.p. 188-189°.

Catalytic hydrogenation of galantamine. 2 g galantamine is dissolved in 10% hydrochloric acid until weakly acid. The solution is agitated in a hydrogen atmosphere in presence of platinum oxide. 189 ml hydrogen is absorbed (one double bond requires 156 ml). The catalyst is filtered off and the solution treated with 25% ammonia and extracted with ether. The residue (2.12 g) after removal of the ether is a rather viscous oil with a light-yellow color. It is purified in the form of the hydrobromide.

The hydrobromide of dihyrogalantamine is almost completely insoluble in acetone, more readily soluble in alcohol from which it crystallizes in colorless, rather large crystals with m. p. 221.5-223°.

The isolated base is recrystallized from petroleum ether to give 0.72 g dihydrogalantamine with m.p. 116-118°.

3.369 mg substance: 8.774 mg CO_2; 2.462 mg H_2O. 6.408 mg substance: 0.273 ml N_2 (19.5°, 742.0 mm). 6.361 mg substance: 0.273 ml N_2 (19.5°, 742.0 mm). Found %: C 71.03; H 8.18; N 4.84, 4.89. $C_{17}H_{23}O_3N$. Calculated %: C 70.59; H 7.9; N 4.87.

Action of acetic anhydride on dihydrogalantamine. 0.35 g of hydrogenated galantamine is dissolved in 4.5 ml freshly distilled pyridine. To the solution is added 4.5 ml acetic anhydride and the mixture heated at 25-35° for 12 hours. After distilling off the pyridine and excess of acetic anhydride in vacuum, addition is made to the residue of 10% hydrobromic acid solution until the reaction is weakly acid. Treatment with acetone precipitates the hydrobromide of acetylated dihydrogalantamine which is filtered at the pump and washed with acetone.

The hydrobromide has m.p. 226-228° after recrystallization from alcohol.

4.105 mg substance: 8.325 mg CO_2; 2.400 mg H_2O. Found %: C 55.31; H 6.54. $C_{17}H_{22}O_3N(COCH_3)\cdot$ $\cdot HBr$. Calculated %: C 55.33; H 6.31.

SUMMARY

1. A new crystalline alkaloid with the composition $C_{17}H_{21}O_3N$ has been isolated from the bulbs of Galanthus Woronowi and has been given the name of galantamine.

2. Galantamine contains one hydroxyl, one methoxyl and one methylimino group. The third oxygen atom is in the reactive-inactive form.

3. Methylation of galantamine with methyl iodide gives the methyl iodide addition product.

4. Hofmann degradation of galantamine gives the decomposition product $C_{18}H_{23}O_3N$.

5. Methylation of the product of degradation of galantamine with methyl iodide gives its methyl iodide addition compound.

6. Galantamine is an unsaturated tertiary base. Hydrogenation yields dihydrogalantamine $C_{17}H_{23}O_3N$.

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ON TO FURTHER ACHIEVEMENTS IN CHEMICAL SCIENCE AND INDUSTRY!

The Soviet people meet the thirty-fifth anniversary of the Great October Socialist Revolution with new victories, and with new and magnificent achievements on the road to communism.

The recently concluded XIXth Congress of the Communist Party of the Soviet Union summarized the results of these victories, and projected a majestic perspective of the building of a communist society.

In the directives of the XIXth Party Congress, in conformance with the Five-Year-Plan, the basic economic principle of socialism has found its bright reflection in the straightforward and scientifically-sound treatise by Comrade Stalin, "Economic Problems of Socialism in the U.S.S.R." The essential characteristics and demands of this principle are: "provision and guarantee of maximum satisfaction for the constantly growing material and cultural demands of the whole society, by way of continuous growth and improvement of socialist production, based upon superior technical arts". [1]

The brilliant composition of Comrade Stalin, "Economic Problems of Socialism in the U.S.S.R.", ideologically arms the party and the Soviet people, and defines the scientific bases for development of socialist economy, and indicates the course of gradual transition from socialism to communism.

For the new five-year period, the projected industrial productivity increase for 1955, as against 1950, is approximately 70%. Together with the enormous growth in industrial, agricultural and consumer goods production, the directives project vigorous progress in all branches of the national economy, considerable increase in national revenue for the U.S.S.R., further elevation of the standard of living and of the cultural level of the Soviet people.

Soviet science in our socialist fatherland has reached unprecedented range and flourish.

If bourgeois science has now rolled down into a bog of reaction, and if it now serves American imperialism in the realization of its predatory plans, then our science is the science of creation, it serves the interests of the nation, and is directed toward the solution of the most important problems of the national economy and culture.

The significance of science in the life of our society increases more and more.

The Party and the Government have built and equipped an enormous network of scientific research institutes, among which are many chemical institutes.

For the scientists, congenial conditions have been created for fruitful creative work, and extensive training of scientific cadre has been provided for.

The number of scientific research institutes, laboratories and other scientific institutions has increased from 1560 in 1939 to 2900 at the beginning of this year. Within the same period, the number of scientific workers has almost doubled. During the past five-year period, the expenditure by the state for the needs of science has amounted to 47.2 billion rubles.

The Academy of Sciences of the U.S.S.R. has become the very world center of science. Under the guidance of the state, the Academy and its scientific establishments have grown to unprecedented, verily gigantic, sizes: The Academy budget, in comparison with prerevolution, has increased almost 700 times, and the number of scientific workers – 60 times. The number of books and journals published by the Academy has also increased almost 25 times. Such a tempo of development of science was never dreamed of, and now cannot be dreamed of by scientists of the capitalist countries. The bourgeois governments, first of all the U.S.A. magnates, do not begrudge the means for that aspect of science which serves for the enslavement and extermination of nations, which justifies and proclaims the cannibalistic plans of its masters.

Our Soviet science will grow and develop further. The Congress directives stipulate: "To expand, during the five-year period to come, the training of scientific and scientific-pedagogical teams, through post-graduate fellowships to the universities and scientific-research institutes, to approximately twice that of the preceding five-year plan.

"To facilitate the work of the scientific-research institutes and the scientific work of the universities, the scientific facilities are to be more amply utilized for solution of the more important problems of development of the national economy, of the general conclusions of advanced tests, experiments to secure wide practical application of scientific discoveries. To cooperate in every way with scholars, to strengthen the bond between science and production in working out theoretical problems in all fields of knowledge" [2].

The party, the government, and Comrade Stalin, personally, have always paid close attention to the chemical industry, to chemical science, and to the training of highly qualified teams of chemists. In Tsarist Russia, the chemical industry was in a state of incubation. Beyond doubt in that time we had some most prominent scholars, among the outstanding chemists of which were, for example, N. N. Zinin, A. M. Butlerov, D. I. Mendeleev, and many others, who enriched not only Russian, but also world knowledge with most important discoveries, but their theoretical investigations and discoveries did not, and could not, find, appropriate practical application in Russia.

Inexhaustible riches lay beneath Russian soil, uninvestigated, unutilized, while chemical products were imported. Only during Soviet rule has domestic chemistry developed and grown stronger. This growth has become singularly noticeable during the years of the Stalin five-year plans. In 1933, Comrade Stalin had already said: "We did not have any major and modern chemical industry. We have it now" [3].

In 1934 the XVII Congress of the All-Union Communist Party (Bolsheviks) – the convention of the victors – resolved: "To achieve definite improvements in the development of the chemical industry, securing broad chemicalization of all branches of the national economy, and the defensability of the country." [4].

As this resolution was fulfilled during the second five-year plan there were great achievements in the chemical industry, particularly in the petroleum, coal, and oil-shale industries, in ferrous and non-ferrous metallurgy, in fertilizers, in the nitrogen industry, in synthetic rubber, plastics and synthetic fibers. In the third five-year plan – the five-year plan of chemistry, and in the fourth – the postwar five-year plan, chemical industry and science achieved even greater and more outstanding successes. Thus, in the fourth five-year plan, i.e., toward the end of 1950, the chemical industry exceeded prewar production by 1.8 times, in the nitrogen fertilizers – by 2.2 times, in the potassium fertilizers – by 1.4 times, and in the phosphate – by 1.9 times. The prewar level of production was exceeded also in other aspects of the chemical industry – in soda, synthetic rubber, plastics and others.

Soviet chemical science has always helped industry actively and efficiently. The success in the petroleum industry, where, through the combined efforts of scholars, geologists and chemists, many new oil fields were discovered and exploited, serves as a striking example. Even more impressive is the example of the exceptionally important work of S. V. Lebedev. His most valuable theoretical investigations form the foundation for the vigorous growth and development of the synthetic rubber industry, so much needed for our national economy. There is no greater happiness for the scholar than to see how his investigations are being rapidly realized for the benefit of his native land.

S. V. Lebedev has said with satisfaction: "The government has decided to convert the success attained by me and my coworkers into the basis for constructing a new branch of industry..... There is not the slightest doubt that only with us, in the country of the building of socialism, is such a great creative range possible. The greatest happiness is to see one's thought converted into a deed of such grandeur."

The directives from the XIXth Congress of the Communist Party of the Soviet Union, for the fifth five-year plan of development for the U.S.S.R. for 1951-1955, projects further the rise of the chemical industry. The more important productivities will increase toward 1955, as compared with 1950, approximately in the following ranges: rubber – by 82%, soda ash – by 84%, caustic soda – by 79%, mineral fertilizers – 88%.

To the scholars and workers in the chemical industry, the XIXth Congress has assigned the task of development, in every way possible, of synthetic rubber production on the basis of petroleum gas utilization, of increase in production of plastics, dyes, raw materials for artificial silk, development of production of synthetic materials – substitutes for the non-ferrous metals. The Congress directives also stipulate increased production outputs for ammonia, sulfuric acid, synthetic rubber, synthetic alcohol, soda, mineral fertilizers, particularly in the granular form, and chemical control agents to combat agricultural plant pests.

Also contemplated is the systematic construction of mineral fertilizer factories, thus securing the indispensable mineral ferilizer production developments for the years to follow. The Congress directives demand a wide incorporation of oxygen into the technological processes of ferrous and non-ferrous metallurgy, into gas production from coals, into the celluloid and the cement industries.

There is no doubt that Soviet chemists will fulfill, with honor, the tasks designed for the five-year plan by the directives. The sum totals of 1951, and the agricultural achievements of the present year, demonstrate that the Soviet people have already achieved considerable success in the fulfillment of the tasks presented by the five-year plan. The chemical industry is now endowed with excellent techniques, has qualified cadres, and the enterprises are not experiencing raw material shortages. The fact is that shortcomings in the work should be decisively removed by means of an extensive development of socialist competition, which will increase productivity, by observing strict economy, finding new reserves. We must develop a creative union between knowledge and practice—the foundations for any scientific and technical progress. Experience has shown that where such accord is established science itself also flourishes, and procures help for the practical workers through better and more rapid solution of production problems.

For the fulfillment of the five-year plan, science has been assigned an active role.

Scientists are responsible for achieving complete utilization of the fuel resources —coal, peat and oil-shales, in the capacity of raw chemical materials. Such raw materials should be burned only after extraction of gas, tar and other substances. Scientists should realize in full the D. I. Mendeleev concept about the complete chemical utilization of petroleum as a raw material, from which we can obtain alcohols, synthetic rubber, dyes and many other materials essential for our national economy. Industry has set before the chemist one more very important problem—the creation of exceptionally durable plastics, which are extra-hard and extra-stable to chemical reactions, and which possess fixed properties which would enable them to replace the valuable metals.

Comrade G. M. Malenkov, in a report of the Party Central Committee for the XIXth Congress, has pointed out a series of shortcomings and distortions which were disclosed by the Central Committee of the All-Union Communist Party (Bolsheviks) in the various departments of science. He pointed out that "in various branches of science there is still incomplete liquidation of monopoly by separate groups of scholars, who brush off new manpower developments, fencing themselves off from criticism, and attempt to solve scientific problems by administrative means. No single branch of science can successfully develop in a stuffy atmosphere of mutual eulogy and overlooking of errors; attempts to affirm the monopoly of separate groups of scholars inevitably engenders stagnation and decay in science" [5].

Every scholar should remember these words, and should answer the call of the Congress "to promote further the advancement of Soviet science, with the aim of attaining first place in world science" [6].

Gigantic, noble, and not an easy aim! But it is within the power of Soviet scientists. Already, various branches of our science have left behind scientists of the capitalist countries. We must surpass them in all branches of science, and we will!

Soviet scientists, armed with the all-triumphant teaching of Marxism-Leninism, inspired by the resolutions of the XIXth Congress of our party, and the speech of our leader, under the guidance of the Communist Party, together with the great coryphaeus of science, Iosif Vissarionivich Stalin, will be in the first ranks of the builders of communism, and the champions of peace throughout all the world.

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SOME PHYSICO-CHEMICAL PROPERTIES OF ARSENOUS ACID ANHYDRIDE

V. M. Borisov and M. G. Gorshtein

Up to the present time, many physico-chemical properties of arsenous acid anhydride have not been precisely determined, nor are there any consistent data concerning the same. Questions of the structures of the various forms of arsenous acid anhydride relate particularly to such properties as melting point, stabilities of its various forms, and others.

The existence of three solid forms of arsenous anhydride is known: two crystalline — octahedral and monoclinic, and one amorphous — vitreous. The data of Smith and Beljars [1], concerning their discovery of three new forms of arsenous acid anhydride, were not confirmed upon examination. As was determined [2], the octrahedral form of arsenous acid anhydride, to which is usually ascribed the formula, As_2O_3, gives a molecular lattice composed of molecules of As_4O_6 (Figure 1, a). The arrangement of the individual molecules in the crystal is similar to that of the carbon atoms in diamond (Fig. 1, b).

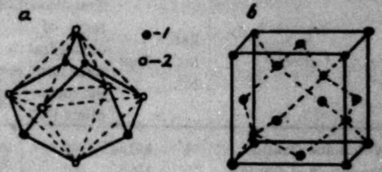


Fig. 1. Arsenous Acid Anhydride.
a - molecule of As_4O_6 in the octahedral modification of the crystal; b - arrangement of As_4O_6 molecules in the octahedral modification of the crystal. 1 - arsenic atoms, 2 - oxygen atoms

The arsenic and oxygen atoms within the molecules are saturated by their own primary valences, while the bonding between the molecules in the lattice is realized by auxiliary valences.

Because the arsenous acid anhydride, in its gaseous state at 800°, forms two-dimensional molecules of As_4O_6, the breaking of only two auxiliary bonds is required for transition of the octahedral form of arsenous acid anhydride into the gaseous state.

The structural monoclinic form of arsenous acid anhydride has not been determined up to the present time, on which matter there is only a series of assumptions. Of these, the best, explaining the properties of arsenous acid anhydride monoclinic structure, is the one presented in Fig. 2 [3]. The composite parts of the lattice, in this case, are bound together by primary valences.

On the average, the transition of the monoclinic form of arsenous acid anhydride to the vapor state requires the rupture of two primary valences; because of further evolution of energy upon saturation of the liberated valences, the activation energy should decrease at the same time: this is confirmed by the smaller heat of sublimation of the monoclinic form, as compared with that of the octahedral.

In view of the fact that the glassy form of arsenous acid anhydride converts readily into the octahedral form, even under normal conditions, some authors make assumptions about the close relationship between the glassy and the octahedral structural forms.

Such an inference appears to be incorrect for two reasons. 1) The glassy form of arsenous acid anhydride transforms readily into the octahedral only under defined conditions, namely, when sufficiently pulverized, and when in the presence of moisture. The authors verified, experimentally, that the glassy arsenous acid anhydride, in various fragment sizes, transformed only partially into the octahedral form, at the surface, after preservation under normal conditions for one year. The basic mass of both the large and the small fragments remained in the glassy form.

2) The sublimation of the vitreous (or glassy) form is considerably smaller than that of the octahedral,

and, as is known, for the vaporization or volatilization processes of various forms of one and the same substance, that form has the greatest volatilization rate whose structure in the solid form is identical with, or has the greatest similarity to, the structure in the gaseous form.

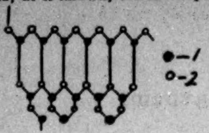


Fig. 2. Monoclinic structural modification of arsenous acid anhydride.
1 - arsenic atoms, 2 - oxygen atoms

On the basis of investigation presented [3], it can be assumed, through the process of "compulsory condensation" of arsenous acid anhydride, that the glassy structural form of arsenous acid anhydride may be represented by an irregular, repetitive atomic lattice.

Data on conditions for the stability of the various forms of solid arsenous acid anhydride, and the melting point of the octahedral form are inconsistent, as can be seen from the table.

These inconsistencies are explained by the fact that the determinations were carried out by different procedures and mainly by indirect methods (by vapor tension, solubility in alkali and in acid, and so forth).

Subject matter No.	Author	Ref. Lit. No.	Year	Transition temp. of octahedral form into the monoclinic (°C)	Melting Point (° C) of the form	
					Octahedral	Monoclinic
1	Welch and Daschak	4	1915	100	251	315
2	Raschton and Daniels	5	1926	100	275	313
3	Smith and Beljars	1	1933	200	–	–
4	Schulman and Schumb	6	1943	-13	–	–

The authors have carried out investigation of transition of the octahedral form of arsenous acid anhydride to the monoclinic, and verification of the melting point for the octahedral form by a direct method involving the use of thermal analysis.

The octahedral form of arsenous acid anhydride, which was obtained by recrystallization from hydrochloric acid as a condensate from a Schumb special sublimator, was heated in a sealed glass tube in a 40 g weighed portion. The content of As_4O_6 in the arsenous acid anhydride used for the heating, was 99.98%. The homogeneity and identity of these samples with that of the octahedral form were verified by microscopic examination.

None of the thermodiagrams taken show the presence of any transition points from arsenous acid anhydride octahedral form to the monoclinic in the range up to the melting point of the octahedral form.

As can be seen from the thermodiagrams (Figures 3 and 3a) the octahedral form starts to melt at 270°.

Before melting starts, an exothermal effect takes place (ascending curve) at the expense of internal structure transformation of the substance.

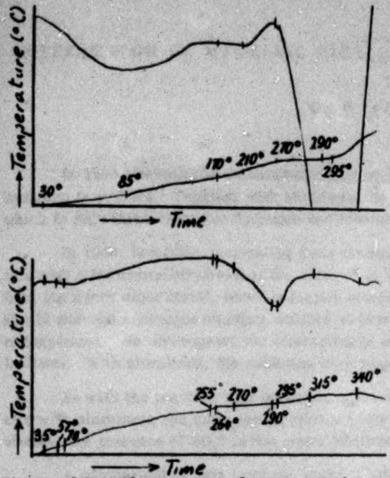
From the thermodiagrams it also follows that the melting point of the octahedral form is polythermal, since melting starts at 270° and is fully terminated at 290-295°.

As is known, arsenous acid anhydride upon heating melts to a viscous mass, which, under the influence of its own weight, slowly changes form. Even at the boiling point, the viscosity of this mass is so great that threads from the viscous mass do not collect into drops.

It can be assumed that, at the start of the melting, there are formed infinite chains of arsenous acid anhydride (As_2O_3) compounds, and that upon further heating there occurs a definite correlation between the finite tetrahedral molecules of the arsenous acid anhydride octahedral form, and the infinite chains being formed at the melting, depending upon the rate of heating, analogous to the correlation between ring structure, S_8, in rhombic sulfur and the infinite chains in plastic sulfur. This evidently gives the polythermal melting temperature of the arsenous acid anhydride octahedral form.

The transition heat for the octahedral to monoclinic form is comparatively small (6100 cal/mole). It is possible that this effect may not be detectable on the thermograms. But the complete melting of the arsenous acid anhydride samples at the melting temperature of the monoclinic form, and the absence of a second melting point on the thermograms, confirm the failure to form noticeable quantities of the monoclinic form when the octahedral form is heated to its melting temperatures.

Thus, it can be considered that the stable form of arsenous acid anhydride is the octahedral form, up to the points of melting.



Figs. 3 and 3a. Thermograms of arsenous acid anhydride fusibility.

SUMMARY

1. The question of the structures of the various forms of arsenous acid anhydride has been defined more accurately, on the analytical basis of the available data on the physico-chemical properties of arsenous acid anhydride.

2. It was ascertained that the melting temperature of arsenous acid anhydride octahedral form is polythermal. Crystals of the octahedral form of arsenous acid anhydride start to melt at 270°C. Complete fusion is effected at 290-295°.

3. The stable form of arsenous acid anhydride is the octahedral, up to the melting temperatures.

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State Institute of Mineral-Chemical Raw Material Stock

[illegible] weight of mixture.

SUMMARY

1. [illegible]

2. It was [illegible]

3. [illegible]

LITERATURE CITED

(1) [illegible] (1946).

(2) [illegible]

(3) [illegible]

(4) [illegible]

(5) E. [illegible] and [illegible], J. Am. Chem. Soc. [illegible]

(6) [illegible]

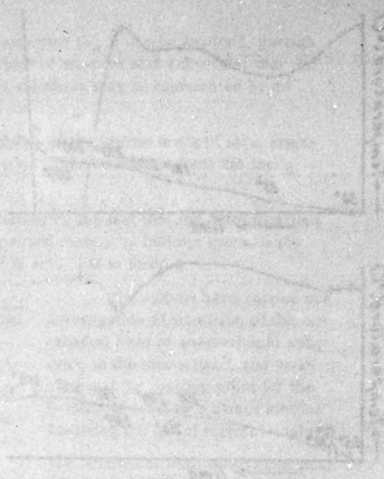

Fig. 1 and 2a. The integral of [illegible]

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INTERACTION OF METALLIC BERYLLIUM WITH SOLID CRYSTALLOHYDRATES

O. P. Alekseeva

In 1905 Mikhailenko demonstrated that when magnesium powder and solid crystallohydrates are mixed, hydrogen is evolved. Together with Mushinsky, he has investigated fifty-three various crystallohydrates, during which in only three cases was hydrogen not evolved.

In 1940, Semishin, proceeding from the assumption that hydrogen evolution during magnesium interaction with solid crystallohydrates is the result of $H^{\cdot}$ ion reduction by magnesium atoms, and that not only magnesium, but every other metal, whose reduction potential ($nEMe/Me^{\cdot\cdot}$) is greater than that of the potential H_2 gas/$2H^{\cdot}$, should undergo analogous reaction, decided to investigate the interaction of aluminum and of zinc with solid crystallohydrates. He investigated the interaction of aluminum with forty two, and of zinc with forty three crystallohydrates. With aluminum, the evolution of hydrogen was not observed in eight cases and with zinc in three cases.

As with the reaction with magnesium, the nature of the crystallohydrates influences the intensity of reaction with aluminum and zinc, the greatest activity being possessed by crystallohydrate salts of hydrochloric acid, whereas the presence of $SO_4^{''}$ in the crystallohydrate lowers considerably its activity toward the metal.

A comparison of data from the works of Mikhailenko and Semishin indicates that aluminum is less reactive toward the water of crystallohydrates in comparison with that of magnesium and that zinc has even less reactivity.

These metals can be arranged in the sequence: Mg-Al-Zn, as regards their activity toward the water of the solid crystallohydrates.

Since the reduction potential of beryllium exceeds, considerably, the potential of H_2 gas/$2H^{\cdot}$, it could be expected, on the basis of the works mentioned, that beryllium should displace hydrogen from the water of the solid crystallohydrates, according to the scheme:

$$Be + 2H \longrightarrow H_2 + Be^{\cdot\cdot},$$

on initial reaction, according to Semishin:

$$Be + 2[Me(H_2O)_{n-1}(OH)^{\prime}]^{+m-1} + 2H^{\cdot} \longrightarrow Be^{\cdot\cdot} + 2[Me(H_2O)_{n-1}(OH)^{\prime}]^{+m-1} + H_2\uparrow.$$

EXPERIMENTAL

In order to conduct the experiments, the authors used a compact lump of beryllium, with a beryllium content of 99.5%, which was available in the laboratory. From the lump were hammered off small fragments; the fragments were finely powdered in a mortar, the fine powder was always sifted through the same sieve, and was preserved in a ground glass stoppered bottle. In the course of the work, it was noticed that freshly-prepared beryllium powder was considerably more active than the powder preserved for several days, after which beryllium powder preserved for twenty-four hours was used in all experiments. The crystallohydrate salts used for the experiments were analytically pure. The salt was ground in a mortar to the finest powder, and a maximum of 0.01 mole was placed in a 50 ml flat-bottomed flask. Into the same flask was placed a weighed quantity of beryllium powder. In order to obtain comparative results, calculation of the weight of crystallohydrate and of metal was made according to the reaction:

$$Be + 2HOH^{\prime} = Be(OH)_2 + H_2.$$

The flask was stoppered with a cork having a tube leading to the gasometer. A one-liter Erlenmeyer flask served for the gasometer. The gas volume was determined by measuring the volume of water which flowed out of the gasometer under the pressure of evolving gas. The flask contents, after stoppering with the cork, were thoroughly mixed by shaking the flask. In those cases where reaction began immediately upon contact of crystallohydrate with metal powder, the latter was not sprinkled into the flask, but was placed in the inclined neck of the flask within a small paper boat; the cork was inserted into the throat of the flask, and the flask tipped into vertical position; the small boat fell to the bottom and the powders were mixed by vigorous shaking of the flask. Thus, the loss of gas was avoided in this case, if reaction started immediately upon direct contact. If reaction did not proceed at room temperature, or if it was in process but the water flow from the gasometer had already ceased, the flask was then placed in a water bath which was gradually heated to boiling, and the reacting mixture was kept on the boiling water bath until the water flow from the gasometer ceased completely; subsequently, the flask was cooled to room temperature, the pressure in the two vessels equalized by the usual procedure, and the volume of displaced water determined, i.e., the gas volume evolved in the 20 to 100° range, and at an external temperature of 100°. The flask was then transferred to a sand bath; the bath temperature was gradually raised to 200°; at this temperature the experiment was continued, until water ceased to flow from the gasometer, and again, the volume of water displaced in the 100-200° interval and at an external temperature of 200°, was measured as in the first case. In each experiment, a qualitative analysis of the gas was carried out to confirm the presence of hydrogen.

The hydrogen volume was not brought to normal pressure, since the error of the experiment, due to uneven mixing, was considerably greater than the correction. It was considered that the hydrogen had been collected at 760 mm pressure, and correction was made only for temperature. Correction for humidity was not made either. Therefore, the experimental data cannot correspond to absolute values, and are used by the authors only for comparative evaluation.

The Effect of the Relative Weight of Beryllium

The completeness of reaction between solid bodies depends upon contact surface; thus, by increasing the relative weights of beryllium, we are creating favorable conditions for hydrogen evolution.

This is confirmed by the following series of experiments (Table 1).

TABLE 1

Expt. Nos.	Crystallohydrate Formula	Weighed Portion		Quantity of Be (equiv)	Evolved H_2 (ml)		H_2 (ml) volume at 0°	H_2O molecules entered into reaction.
		of salt	Be		to 100° and at 100°	to 200° and at 200°		
40	$K_2Cr_2(SO_4)_4 \cdot 24H_2O$	2.5	0.27	1	87	43	124.3	4.44
		2.5	0.54	2	115	70	172.3	6.16
53	$CoCl_2 \cdot 6H_2O$	1.19	0.13	1	113	120	215.3	3.84
		1.19	0.27	2	85	250	313.3	5.59
		1.19	0.40	3	165	225	360.9	6.45
47	$(NH_4)_2Fe_2(SO_4)_4 \cdot 24\,H_2O$	2.41	0.27	1	160	10	161.1	5.74
		2.41	0.54	2	160	65	211.8	7.56
23	$CdCl_2 \cdot 2^{1/2}\,H_2O$	2.88	0.11	1	150	75	208.22	1.89
		2.88	0.23	2	225	165	360.9	3.22
		2.88	0.34	3	165	200	339.63	3.03
37	$SnCl_2 \cdot 2H_2O$	2.26	0.09	1	95	55	142.2	1.28
		2.26	0.14	1.5	95	95	176.4	1.58
		2.26	0.18	2	185	140	301.8	2.78
		2.26	0.27	3	215	175	362.1	3.24
44	$FeCl_3 \cdot 6H_2O$ (yellow)	1.35	0.14	1	165	110	227.5	4.06
		1.35	0.20	1.5	225	167	364.0	6.50
		1.35	0.27	2	265	155	390.0	6.96
		1.35	0.34	2.5	Gas collection unsuccessful; gas evolution so violent gasometer breaks.			
		1.35	0.40	3				
45	$FeSO_4 \cdot 7H_2O$	1.39	0.16	1	0	0	–	–
		1.39	0.32	2	0	0	–	–
		1.39	0.48	3	0	0	–	–
3	$Na_2SO_3 \cdot 7H_2O$	1.26	0.16	1	0	0	–	–
		1.26	0.32	2	0	0	–	–
5	$Na_2B_4O_7 \cdot 10H_2O$	3.81	0.45	1	0	0	–	–
		3.81	0.90	2	0	0	–	–

An increase in the relative weight of beryllium causes an increase in volume of hydrogen evolution. In those cases where intense reaction proceeded, with large heat evolution, and the mixture heated up strongly, as took place with the chlorides of cobalt, cadmium, divalent lead and trivalent iron (Experiments 53, 23, 37 and 44), a large excess of beryllium, of two or more equivalents—produced hydrogen evolution in volume exceeding the theoretical possible, according to the reaction:

$$Be + 2\dot{H}OH' \longrightarrow Be(OH)_2 + H_2. \qquad (I)$$

In those cases where reaction with an equivalent weight of beryllium does not take place, a relative increase in the beryllium does not cause reaction (Experiments 45, 3 and 6).

On the basis of orientative experiments, the author has investigated the interaction of beryllium with fifty-nine solid crystallohydrates, representing combinations of twenty-three cations and seventeen anions. In all instances, to obtain comparative results, the weight of beryllium powder taken was twice that of the the calculated theoretical, according to Reaction (I).

All experiments were conducted in

TABLE 2

Expt. Nos.	Crystallohydrate formula	Weighed portion salt	Weighed portion Be	Quantity of Be (equiv)	H_2 (ml) evolved to 100°	H_2 (ml) evolved to 200°	H_2(ml) volume at 0°	H_2O molecules entered into reaction.
1	2	3	4	5	6	7	8	9
1	$Na_2CO_3 \cdot 10H_2O$	1.43	0.45	2	25	0	23.13	0.41
2	$Na_2SO_4 \cdot 10H_2O$	1.61	0.45	2	0	0	–	–
3	$Na_2SO_3 \cdot 7H_2O$	1.26	0.32	2	0	0	–	–
4	$Na_2S_2O_3 \cdot 5H_2O$	2.48	0.45	2	12	0	–	–
5	$Na_2HPO_4 \cdot 12H_2O$	1.79	0.54	2	15	0	11.2	0.10
6	$Na_2B_4O_7 \cdot 10H_2O$	3.81	0.90	2	0	0	13.9	0.13
7	$NaC_2H_3O_2 \cdot 3H_2O$	1.36	0.27	2	0	0	–	–
8	$Na_2[Fe(CN)_5NO] \cdot 2H_2O$	2.89	0.18	2	0	0	–	–
9	$NaC_4H_4O_6 \cdot 4H_2O$	2.82	0.36	2	0	0	–	–
10	$K_4Fe(CN)_6 \cdot 3H_2O$	4.22	0.27	2	0	0	–	–
11	$K_2B_4O_7 \cdot 5H_2O$	1.62	0.23	2	0	0	–	–
12	$(NH_4)_3C_6H_5O_7 \cdot H_2O$	2.61	0.09	2	0	0	–	–
13	$(NH_4)_2C_2O_4 \cdot H_2O$	1.24	0.09	2	0	0	–	–
14	$MgSO_4 \cdot 7H_2O$	2.46	0.63	2	0	0	–	–
15	$Mg(NO_3)_2 \cdot 6H_2O$	1.28	0.27	2	0	0	–	–
16	$MgCl_2 \cdot 6H_2O$	2.03	0.54	2	0	320	293.9	2.62
17	$Ca(NO_3)_2 \cdot 4H_2O$	2.63	0.36	2	0	0	–	–
18	$Ca(C_2H_3O_2)_2 \cdot 2H_2O$	1.94	0.18	2	0	15	13.9	0.13
19	$BaCl_2 \cdot 2H_2O$	2.44	0.18	2	0	23	21.4	0.19
20	$ZnSO_4 \cdot 7H_2O$	2.88	0.63	2	230	0	213.6	1.9
21	$Zn(C_2H_3O_2)_2 \cdot 2H_2O$	2.19	0.18	2	0	0	–	–
22	$Zn(NO_3)_2 \cdot 6H_2O$	2.98	0.54	2	0	0	–	–
23	$CdCl_2 \cdot 2^{1/2} H_2O$	2.88	0.23	2	225	165	360.9	3.22
24	$CdSO_4 \cdot 8^{8/3} H_2O$	2.57	0.24	2	55	15	64.78	0.58
25	$Cd(NO_3)_2 \cdot 4H_2O$	1.54	0.18	2	0	0	–	–
26	$CuCl_2 \cdot 2H_2O$	3.41	0.36	2	180	175	330.8	1.48
27	$CuSO_4 \cdot 5H_2O$	2.5	0.45	2	125	25	140.7	1.26
28	$Cu(NO_3)_2 \cdot 6H_2O$	2.96	0.54	2	0	0	–	–
29	$Cu(C_2H_3O_2)_2 \cdot H_2O$	3.99	0.18	2	0	35	32.28	0.15
30	$Cu(NH_3)_4Cl_2 \cdot H_2O$	2.21	0.09	2	0	0	–	–
31	$Cu(NH_4)_2(SO_4)_2 \cdot 6H_2O$	4.0	0.54	2	260	10	249	2.22
32	$Cu(NH_4)_2Cl_4 \cdot 2H_2O$	2.78	0.18	2	160	190	322.91	2.88
33	$Bi(NO_3)_3 \cdot 5H_2O$	3.05	0.45	2	0	0	–	–
34	$Al_2(SO_4)_3 \cdot 18H_2O$	3.33	0.81	2	225	50	253.6	4.53
35	$K_2Al_2(SO_4)_4 \cdot 24H_2O$	1.19	0.27	2	50	43	87.3	6.24
36	$(NH_4)_2Al_2(SO_4)_4 \cdot 24H_2O$	1.13	0.27	2	48	52	93.0	6.64
37	$SnCl_2 \cdot 2H_2O$	2.26	0.18	2	185	140	301.8	2.78
38	$CrCl_3 \cdot 6H_2O$	1.33	0.27	2	125	225	328.0	5.86
39	$Cr_2(SO_4)_3 \cdot 18H_2O$	3.57	0.81	2	0	0	–	–
40	$K_2Cr_2(SO_4)_4 \cdot 24H_2O$	2.50	0.54	2	115	70	172.3	6.16
41	$Cr(NO_3)_3 \cdot 9H_2O$	2.00	0.40	2	0	0	–	–
42	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	3.25	0.27	2	0	0	–	–
43	$HgNO_3 \cdot H_2O$	5.61	0.18	2	0	0	–	–
44	$FeCl_3 \cdot 6H_2O$	1.35	0.27	2	265	155	390.0	6.96
45	$FeSO_4 \cdot 7H_2O$	1.39	0.32	2	0	0	–	–

TABLE 2 — (continued)

Expt. Nos.	Crystallohydrate formula	Weighed portion		Quantity of Be (equiv)	H_2(ml) evolved		H_2(ml) volume at 0°	H_2O molecules entered into reaction
		salt	Be		to 100°	to 200°		
1	2	3	4	5	6	7	8	9
46	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	3.92	0.54	2	0	80	74.5	0.67
47	$(NH_4)_2Fe_2(SO_4)_4 \cdot 24H_2O$	2.41	0.54	2	160	65	211.8	7.56
48	$Fe(NO_3)_3 \cdot 9H_2O$	4.04	0.81	2	0	0	–	–
49	$FePO_4 \cdot 2H_2O$	1.87	0.18	2	0	0	–	–
50	$Fe_3(PO_4)_2 \cdot 8H_2O$	2.51	0.36	2	0	0	–	–
51	$NiSO_4 \cdot 7H_2O$	2.80	0.63	2	0	0	–	–
52	$Ni(NH_4)_2(SO_4)_2 \cdot 6H_2O$	3.95	0.54	2	0	0	–	–
53	$CoCl_2$ $6H_2O$ calculated with HCl	1.19	0.27	2	85	250	313.3 +14.5	5.59 5.86
54	$CoSO_4 \cdot 7H_2O$	0.84	0.19	2	0	0	–	–
55	$Co(NO_3)_2 \cdot 6H_2O$	2.91	0.54	2	0	0	–	–
56	$Co(C_2H_3O_2)_2 \cdot 4H_2O$	2.49	0.36	2	36	8	41.0	0.37
57	$MnCl_2 \cdot 4H_2O$	1.98	0.36	2	0	115	109	0.97
58	$Mn(NO_3)_2 \cdot 6H_2O$	1.44	0.27	2	0	0	–	–
59	$Ba(OH)_2 \cdot 8H_2O$	3.16	0.72	2	360	5	333.26	2.98

multiple repetition.

Results of the experiments are quoted in Table 2.

Analysis of the Experimental Results

In Table 2 are collected the results obtained from the study of fifty-nine various crystallohydrates with beryllium powder.

All calculations for the quantity of water of crystallization entering into reaction were made according to the equation $Be + 2H'OH' = Be(OH)_2 + H_2$, in contradistinction to which there were obtained values considerably exceeding the possible theoretical in a number of cases. This was done for the purpose of comparing the results obtained by the author with the results of Mikhailenko and Semishin, using magnesium, aluminum and zinc, where the calculations were made according to the above-quoted equation.

I. In four instances (Experiments 23, 32, 37 and 44) the quantity of water of crystallization entered into reaction was more than 100%. These are the cases where the reaction started with a sudden impetus and with considerable heating up. It could be assumed that due to the high temperature developed at the abrupt start of the reaction, as a result of the reaction of beryllium with the crystallization water of the crystallohydrates, the beryllium hydroxide formed decomposed with liberation of water $Be(OH)_2 = BeO + H_2O$, since beryllium hydroxide can stand drying up to 100°, but upon stronger heating splits off water, transforming into BeO. In its turn the water liberated from $Be(OH)_2$ entered into reaction with the beryllium powder, for which reaction the catalyst was the salt contained in the reaction mixture. The author is basing this assumption upon the work of Mikhailenko and Mushinski, who demonstrated that the catalyst for the reaction of metallic magnesium with water appeared to be those substances whose crystallohydrates react with magnesium, and also upon the following observations which have been made in the process of the author's work.

1) Upon heating a mixture of the crystallohydrate powder with beryllium powder, considerable water condensed on the wall of the flask in a number of instances. When this water, running down the walls of the flask, dropped onto the mixture, this provoked an intense evolution of hydrogen in some cases, for example, in the experiments with $CuSO_4 + 5H_2O$ (experiment 27), with $CuCl_2 \cdot 6H_2O$ (experiment 52); in other instances the dropping of water onto the crystallohydrate and beryllium mixture remained without results, even upon heating to 200°, as for example with $Zn(C_2H_3O_2)_2 \cdot 2H_2O$ (experiment 21), with $K_4Fe(CN)_6 \cdot 3H_2O$ (experiment 10) and with $Na_2B_4O_7 \cdot 10H_2O$ (experiment 6). Thus, as regards the reaction of beryllium with water, the catalytic salts for the reaction could be non-catalytic.

2) In two cases (experiment 23 with $CdCl_2 \cdot 2^{1/2}$ H_2O and experiment 24 with $CdSO_4 \cdot {}^8/_3$ H_2O) there was an intensive evolution of hydrogen without a heating up of the mixture, upon wetting with water the mass which had remained in the flask after cessation of the previous hydrogen evolution due to the 200° heating.

In the remaining instances, such observations were not made, therefore, it is not possible to say anything definite, but in any case there is still the phenomenon of reaction activation between the metal and water.

3) Some salts which are devoid of crystallization water do not react with beryllium powder in the dry state, but when moist, or in the form of a water suspension, react with hydrogen evolution. Thus, for example, a water suspension of Cu_2Cl_2 with beryllium powder gives an intense reaction, with heat and violent hydrogen evolution, hydrogen chloride, and copper reduction.

4) In some instances the crystallohydrates, reacting with beryllium powder only upon heating (Experiment 24 with $CdSO_4 \cdot {}^8/_3$ H_2O and experiment 27 with $CuSO_4 \cdot 5H_2O$), react very vigorously in the moist state without heating, with an evolution of heat for the overall mass, violent evolution of hydrogen, and metal reduction.

The cases quoted can be summed up in the conception of the reaction activation of beryllium with water. It was of great interest and important, to explain the mechanism of activation, and to clarify the role of the activator in the reaction. Investigation of the reaction products could have given results in this sense, however, investigation of the mixture in this direction was not carried out. The authors will utilize the observed activation phenomenon only to base their assumption about the process of hydrogen evolution from the mixture of crystallohydrate with beryllium powder in those cases where the hydrogen evolution is greater than that theoretically possible according to the standard reaction scheme between metal and water. It is possible that in the remainder of the cases where heating was conducted at 200° the process went analogously, but less intensely, and thus the amount of crystallization water entering into reaction with beryllium did not exceed 100%. Without an investigation of the reaction products it is difficult to express anything more definite.

II. The influence of the nature of the crystallohydrate upon the beryllium activity as regards crystallization water was very clearly shown. In some cases reaction occurred upon mixing, in other cases upon light heating, and in still others reaction did not occur even upon heating to 200°; sometimes hydrogen was evolved very slowly and gradually, in other cases the hydrogen evolution proceeded very violently, occasionally with explosion-like violence; the intensity of the reaction occasionally shows two or three maxima (experiment 37 with $SnCl_2 \cdot 2H_2O$ and experiment 44 with $FeCl_3 \cdot 6H_2O$, and others).

The last case indicates that the various molecules with added neutral water have bonds in the aqua-complex of unequal stability with an ion-complexing agent, and consequently with varying degree of proton mobility.

Semishin has expressed the assumption that in the inner sphere of the aqua-complex the water molecules are arranged in layers, distinguished by attraction energy of the neutral addendum, starting from the fact that neither he, nor Mikhailenko, have been able to induce interaction between powdered Mg, Al or Zn metal with more than 50% of the crystallization water. The maxima in the intensity of crystallohydrate reaction with beryllium, observed by the author, confirm this assumption.

The absence of interaction between beryllium and crystallohydrate water was established in thirty-two instances out of fifty-nine; six crystallohydrates started to react at temperatures above 100°, (experiments 16, 18, 19, 29, 46 and 57); of four, the reaction terminated at 100°, and further heating to 200° did not procure reaction (tests 1, 4, 5, 20); in six cases reaction started within a few seconds after mixing, with sudden violence and heat evolution of the mixture (tests 23, 26, 37, 44, 53); in the remainder of cases reaction proceeded with moderate speed, starting in the interval 40-70°. The rate of hydrogen evolution for a series of crystallohydrates has two maxima: a first one up to 100°, and a second between 100 and 200°. The quantity of crystallization water entering into reaction fluctuates from 1.03% in $Na_2HPO_4 \cdot 12H_2O$, to 97.62% in $CrCl_3 \cdot 6H_2O$, not counting those four crystallohydrates whose quantity of water entered into reaction exceeds 100% (tests 23, 32, 37, 44). Thus we see that the nature of the crystallohydrates affects the results of the reaction with extraordinarily large magnitude. In order to better ascertain the influence of the crystallohydrate nature, they were grouped into several tables according to the anions.

As table 3 shows, of the chlorides, the crystallohydrates of the metals belonging to the iron family, and salts of the so-called heavy metals, enter most actively into reaction. The very small activity of the $MnCl_2 \cdot 4H_2O$

TABLE 3

Expt. No.	Crystallohydrate formula	Volume H_2(ml) at 0°	H_2O molecules entered into reaction
1	2	3	4
16	$MgCl_2\cdot 6H_2O$	293.9	2.62
19	$BaCl_2\cdot 2H_2O$	21.4	0.19
23	$CdCl_2\cdot 2^1/_2H_2O$	360.9	3.22
26	$CuCl_2\cdot 2H_2O$	330.8	1.48
37	$SnCl_2\cdot 2H_2O$	301.8	2.78
38	$CrCl_3\cdot 6H_2O$	328.0	5.86
44	$FeCl_3\cdot 6H_2O$	390.0	6.96
53	$CoCl_2\cdot 6H_2O$	313.3	5.59
57	$MnCl_2\cdot 4H_2O$	109.0	0.97
32	$Cu(NH_4)_2Cl_4\cdot 2H_2O$	322.91	2.86
30	$Cu(NH_3)_4Cl_2\cdot H_2O$	0	0

TABLE 4

Expt. No.	Crystallohydrate formula	Volume H_2(ml) at 0°	H_2O molecules entered into reaction
1	2	3	4
2	$Na_2SO_4\cdot 10H_2O$	0	0
14	$MgSO_4\cdot 7H_2O$	0	0
20	$ZnSO_4\cdot 7H_2O$	213.6	1.9
24	$CdSO_4\cdot {}^8/_3H_2O$	64.78	0.58
27	$CuSO_4\cdot 5H_2O$	140.7	1.26
31	$Cu(NH_4)_2(SO_4)_2\cdot 6H_2O$	249	2.22
34	$Al_2(SO_4)_3\cdot 18H_2O$	253.6	4.53
35	$K_2Al_2(SO_4)_4\cdot 24H_2O$	87.3	6.24
36	$(NH_4)_2Al_2(SO_4)_4\cdot 24H_2O$	93.0	6.64
39	$Cr_2(SO_4)_3\cdot 18H_2O$	–	0
40	$K_2Cr_2(SO_4)_4\cdot 24H_2O$	172.3	6.16
45	$FeSO_4\cdot 7H_2O$	–	0
46	$Fe(NH_4)_2(SO_4)_2\cdot 6H_2O$	74.5	0.67
47	$(NH_4)_2Fe_2(SO_4)_4\cdot 24H_2O$	211.8	7.56
51	$NiSO_4\cdot 7H_2O$	–	0
52	$Ni(NH_4)_2(SO_4)_2\cdot 6H_2O$	–	0
54	$CoSO_4\cdot 7H_2O$	–	0

represents an exception. The chlorides of the alkaline earth metal crystallohydrates display little activity, and of all the chlorides investigated, only the chloride of copper ammoniate failed to react at all with beryllium.

A comparison of data in tables 3 and 4 demonstrates that the crystallohydrates of the sulfates are considerably less reactive toward beryllium than the crystallohydrates of the chlorides. Of eleven investigated chlorides, only one, the chloride of copper ammoniate, failed to react with beryllium, and only had a percentage of water of crystallization entered into reaction which was less than 10%, the majority having a percentage considerably higher 50 to that approaching 100% and four leaving considerably higher than 100%. And at the same time, of the seventeen sulfates investigated, seven did not react with beryllium, and the remaining had a quantity of percentage water of crystallization entered into reaction which did not exceed 37%, with one exception; in the majority of cases (seven out of nine) this percentage fluctuated from 21 to 27%. Among the sulfates, the inactive proved to be the crystallohydrates of sodium, magnesium, chromium, and also all of the metals of the iron family.

Double salts and alums displayed greater activity than the simple ones. Thus, for example, $Cr_2(SO_4)_3\cdot 18H_2O$ does not react, but in potassium chromate alum it was possible to decompose 25% of the water of crystallization. This phenomenon is also observed among the chlorides, $CuCl_2\cdot 2H_2O$ gives 73.84% of water entered into reaction, and $Cu(NH_4)_2Cl_4\cdot 2H_2O$ -144.15%. The exception to this situation is nickel, for which the sulfate – both simple and double with ammonia – does not react with beryllium.

Thus, the crystallohydrates of the sulfates in all cases manifest less activity with beryllium as compared with the chlorides, exactly the same as was noted in the works of Mikhailenko and Semishin with magnesium, aluminum and zinc.

In experiments 22, 23, 41, 43, 48 and 58, considerable volume of gas was collected (from 50 to 135 ml), but it was found to be pure nitric oxide. Thus, from the eleven investigated nitrates not one reacted with beryllium to evolve hydrogen. The presence in the crystallohydrate of the nitrate ion renders it entirely inactive as regards to beryllium.

From a comparison of the data in tables 6 and 4, it can be seen that the anion of acetic acid, in all cases except one (test 56), exerts an inhibitory action upon the interaction of the crystallohydrate with beryllium which is considerably greater than that of the SO_4'' ion.

The anions can be arranged in a sequence, according to decreasing activity, as regards the effect of the anion upon the activity of the crystallohydrate with beryllium:

$$Cl' > SO_4'' > (C_2H_3O_2)' > NO_3'$$

TABLE 5

Nitrates

Test No.	Crystallohydrate formula	Total H_2 separated (in ml)
15	$Mg(NO_3)_2 \cdot 6H_2O$	0
17	$Ca(NO_3)_2 \cdot 4H_2O$	0
22	$Zn(NO_3)_2 \cdot 6H_2O$	0
25	$Cd(NO_3)_2 \cdot 4H_2O$	0
28	$Cu(NO_3)_2 \cdot 6H_2O$	0
33	$Bi(NO_3)_3 \cdot 5H_2O$	0
41	$Cr(NO_3)_3 \cdot 9H_2O$	0
43	$HgNO_3 \cdot H_2O$	0
48	$Fe(NO_3)_3 \cdot 9H_2O$	0
55	$Co(NO_3)_2 \cdot 6H_2O$	0
58	$Mn(NO_3)_2 \cdot 6H_2O$	0

TABLE 6

Acetates

Test No.	Crystallohydrate formula	H_2 vol. (ml at 0°)	H_2O molecules entered into reaction
7	$NaC_2H_3O_2 \cdot 3H_2O$	0	0
18	$Ca(C_2H_3O_2)_2 \cdot 2H_2O$	13.9	0.13
21	$Zn(C_2H_3O_2)_2 \cdot 2H_2O$	0	0
29	$Cu(C_2H_3O_2)_2 \cdot H_2O$	32.28	0.15
42	$Pb(C_2H_3O_2)_2 \cdot 3H_2O$	0	0
56	$Co(C_2H_3O_2)_2 \cdot 4H_2O$	41.0	0.37

This sequence we arranged on the basis of a study of the reaction with beryllium of ten crystallohydrates with the Cl^- ion, seventeen with the $SO_4^=$ ion and six with the $(C_2H_3O_2)'$ ion, and eleven with the NO_3^- ion. The remaining fifteen crystallohydrates are found to be salts of various cations and anions repeated once or twice in the tests. Thus, as for an arrangement of similar type for all of the anions, there are insufficient data for the time being.

On the basis of the data in table 7, it can be assumed that the $PO_4^{\equiv}$ ion and the organic acid anions will, as a rule, exert an inhibitory effect on the reaction.

TABLE 7

Crystallohydrates of the Salts of Various Acids

Test No.	Crystallohydrate formula	H_2 vol. (ml) at 0°	H_2O molecules entered into reaction	Test No.	Crystallohydrate formula	Vol. of H_2 (ml) at 0°	H_2O molecules entered into reaction
1	$Na_2CO_3 \cdot 10H_2O$	23.13	0.41	10	$K_4Fe(CN)_6 \cdot 3H_2O$	–	0
3	$Na_2SO_3 \cdot 7H_2O$	–	0	11	$K_2B_4C_7 \cdot 5H_2O$	–	0
4	$Na_2S_2O_3 \cdot 5H_2O$	11.2	0.10	12	$(NH_4)_3C_6H_5O_7 \cdot H_2O$	–	0
5	$Na_2HPO_4 \cdot 12H_2O$	13.9	0.13	13	$(NH_4)_2C_2O_4 \cdot H_2O$	–	0
6	$Na_2B_4O_7 \cdot 10H_2O$	–	0	49	$FePO_4 \cdot 2H_2O$	–	0
8	$Na_2[Fe(CN)_5NO] \cdot 2H_2O$	–	0	50	$Fe_3(PO_4)_2 \cdot 8H_2O$	–	0
9	$NaKC_4H_4O_6 \cdot 4H_2O$						

As regards the activity of beryllium with the crystallohydrates, in comparison with magnesium, aluminum and zinc, the beryllium fails to react with a great many more crystallohydrates than the metals mentioned, but in those cases where reaction does occur, beryllium reacts with considerable more activity than the metals mentioned.

The table 8 which follows illustrates this situation.

TABLE 8

Metals	The number of investigated crystallohydrates	The number of crystallohydrates		Crystallohydrate percent, where H_2O entered into reaction $>10\%$	Maximum % of H_2O entered into reaction	Crystallohydrate formula, from which the maximum of H_2O was successfully split.
		Non-reacting	Reacted			
Be	59	31	28	75	144.15	$Cu(NH_4)_2Cl_4 \cdot 2H_2O$
Mg	53	3	50	44	39.1	$CoCl_2 \cdot 6H_2O$
Al	42	8	34	23.5	51.3	$FeCl_2 \cdot 4H_2O$
Zn	43	5	38	11.5	29.3	$NiCl_2 \cdot 6H_2O$

TABLE 9

Interaction of the Crystallohydrates of the Chlorides with Be, Mg, Al and Zn at 200°

No.	Crystallohydrate formula	Entered into reaction with the water of crystallization							
		Be (Alekseeva data)		Mg (Mikhailenko data)		Al (Semishin data)		Zn (Semishin data)	
		%	Mol.	%	Mol.	%	Mol.	%	Mol.
1	$MgCl_2 \cdot 6H_2O$	43.42	2.62	11.87	0.7	1.63	0.10	1.3	0.08
2	$BaCl_2 \cdot 2H_2O$	9.55	0.19	0	0	3.6	0.07	2.99	0.06
3	$CdCl_2 \cdot 2^1/_2H_2O$	128.9	3.22	Vigorous reaction upon grinding		7.1	0.14	Vigorous reaction upon grinding	
4	$CuCl_2 \cdot 2H_2O$	73.84	1.48	5.8	0.12	8.6	0.17	5.6	0.11
5	$SnCl_2 \cdot 2H_2O$	134.74	2.78	Vigorous reaction upon grinding		21.8	0.44	(8.0)	(0.16)
6	$CrCl_3 \cdot 6H_2O$	97.62	5.86	21.11	1.27	Vigorous reaction upon grinding		(5.94)	(0.36)
7	$FeCl_3 \cdot 6H_2O$	116.17	6.98	Vigorous reaction upon grinding		22.1	1.33	6.6	0.40
8	$CoCl_2 \cdot 6H_2O$	93.16	5.59	39.19	2.35	31.7	1.90	22.9	1.37
9	$NiCl_2 \cdot 6H_2O$	–	–	25.35	1.34	24.7	1.48	29.3	1.76
10	$MnCl_2 \cdot 4H_2O$	24.33	0.97	25.25	1.01	1.30	0.07	5.8	0.23
11	$FeCl_2 \cdot 4H_2O$	–	–	28.56	1.14	51.3	2.05	9.1	0.36
12	$Cu(NH_4)_2Cl_4 \cdot 2H_2O$	144.15	2.88	–	–	–	–	–	–

TABLE 10

Interaction of the Crystallohydrates of the Sulfates with Be, Mg, Al and Zn

No.	Crystallohydrate formula	Entered into reaction with the water of crystallization							
		Be (Alekseeva data)		Mg (Mikhailenko data)		Al (Semishin data)		Zn (Semishin data)	
		%	Mol.	%	Mol.	%	Mol.	%	Mol.
1	$Na_2SO_4 \cdot 10H_2O$	0	0	3.64	0.36	1.5	0.15	0	0
2	$CaSO_4 \cdot 2H_2O$	–	–	0	0	–	–	–	–
3	$MgSO_4 \cdot 7H_2O$	0	0	7.21	0.50	2.1	0.15	1.7	0.12
4	$ZnSO_4 \cdot 7H_2O$	27.24	1.9	23.5	1.63	1.5	0.1	1.0	0.07
5	$CdSO_4 \cdot {}^8/_3 H_2O$	21.67	0.58	6.21	0.50	0	0	3.4	0.27
6	$CuSO_4 \cdot 5H_2O$	25.13	1.26	5.63	0.28	1.4	0.07	1.2	0.06
7	$MnSO_4 \cdot 5H_2O$	–	–	12.3	0.86	0.89	0.04	0.72	0.04
8	$FeSO_4 \cdot 7H_2O$	0	0	0	0	0	0	2.8	0.2
9	$NiSO_4 \cdot 7H_2O$	0	0	4.08	0.28	2.7	0.19	–	–
10	$CoSO_4 \cdot 6H_2O$	0	0	9.44	0.57	0	0	1.04	0.06
11	$Al_2(SO_4)_3 \cdot 18H_2O$	25.16	4.53	6.44	1.16	0.90	0.1	1.99	0.36
12	$K_2Al_2(SO_4)_4 \cdot 24H_2O$	26.0	6.24	17.39	4.17	2.90	0.59	2.23	0.54
13	$Cr_2(SO_4)_3 \cdot 18H_2O$	0	0	–	–	–	–	0	0
14	$K_2Cr_2(SO_4)_4 \cdot 24H_2O$	25.65	6.16	15.73	3.78	1.38	0.33	1.8	0.43
15	$(NH_4)_2Fe_2(SO_4)_4 \cdot 24H_2O$	31.52	7.56	–	–	0	0	1.20	0.29
16	$(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$	11.09	0.67	8.14	0.49	0	0	1.3	0.08

In all cases the beryllium activity, as regards the crystallohydrates of the chlorides, exceeds the activity of aluminum and zinc many-fold, and exceed considerably the magnesium activity, and only as regards the $MnCl_2 \cdot 4H_2O$, are the activity of the beryllium and the magnesium the same (table 9).

For the sulfates, the picture obtained is somewhat different (table 10).

As the data of table 10 show, this picture is considerably variegated. Thus, $MgSO_4 \cdot 7H_2O$ and $NiSO_4 \cdot 7H_2O$ do not give reaction with beryllium but react with the remaining three metals; $CdSO_4 \cdot {}^8/_3H_2O$, Mohr's salt and ammonia the ferric alums of these [illegible] react only with aluminum but $FeSO_4 \cdot 7H_2O$ on the contrary, reacts only with zinc; $Na_2SO_4 \cdot 10H_2O$, does not react with zinc or beryllium. For all four metals the interaction with the various crystallohydrates of the sulfate is clearly seen to be an inhibitory role for the SO_4'' ion, in contrast to the Cl' ion.

For the salt series there is greater activity of beryllium, as regards the sulfates, than of aluminum and zinc, and even of magnesium, but in this last situation there are exceptions, where the beryllium does not react and the magnesium displays activity – these are the sulfates of sodium, magnesium, cobalt and nickel.

SUMMARY

1. Metallic beryllium powder reacts with the water of crystallization of solid crystallohydrates.

2. One of the reaction products is found to be hydrogen.

3. The quantity of crystallohydrate water which enters into reaction is increased with an increase in the relative amount of beryllium, but within certain limits.

4. The reaction of beryllium with water can be activated at ordinary temperatures both by crystallohydrates reacting in the solid state with beryllium and by some anhydrous, practically water-insoluble salts.

5. The basic reaction between beryllium and the water of crystallization, which proceeds according to the scheme $Be + 2HOH' \longrightarrow Be(OH)_2 + H_2$, is complicated in those cases where the process occurs with considerable heating of the reaction mixture, in that $Be(OH)_2$ loses water, and the evolving water is decomposed by the metallic beryllium under the activating influence of the crystallohydrate.

6. In a number of cases, upon reaction of beryllium with the crystallohydrates of chlorides, there is observed, along with hydrogen, the evolution of hydrogen chloride, and the reduction of the salt cation to the metal.

7. The nature of the crystallohydrate affects the intensity of the reaction to an extreme degree. The quantity of water entered into reaction fluctuates from zero to 144%. Some crystallohydrates enter into reaction with beryllium upon direct contact, others require heating to various degrees, and yet others do not react, even when heated up to 200°.

8. The crystallohydrates of the chlorides possess the greatest activity with beryllium.

9. The crystallohydrates of the nitrates are entirely inactive toward beryllium.

10. The presence of the SO_4'' ion in the crystallohydrate and $(C_2H_3O_2)'$ strongly decrease the activity of the crystallohydrates toward beryllium, and at the same time, the presence of the $(C_2H_3O_2)'$ ion decreases the activity to a greater degree than the SO_4'' ion.

11. The crystallohydrates of the double salts and of alum react with beryllium more actively than the corresponding simple salts.

12. Of the cations, those of sodium and the alkaline earth metals impart the smallest activity to the crystallohydrates. The chlorides of the metals of the iron family and the heavy metals possess the greatest activity, The most active of the simple salts are: $SnCl_2 \cdot 2H_2O$, $CdCl_2 \cdot 2{}^1/_2H_2O$, $FeCl_3 \cdot 6H_2O$, $CrCl_3 \cdot 6H_2O$, $CoCl_2 \cdot 6H_2O$ and $CuCl_2 \cdot 2H_2O$.

13. In all cases beryllium is considerably more active toward the crystallization water of the solid crystallohydrates of chloride, than are magnesium, aluminum and zinc. According to decreasing activity, these metals are arranged in the sequence Be–Mg–Al–Zn.

14. Regardless of the great activity of beryllium, it is not possible to decompose all of the water of crystallization in a majority of the crystallohydrates. The interaction of a crystallohydrate with beryllium occurs stepwise, the intensity of hydrogen evolution having two, and in some cases three, maxima for the majority of crystallohydrates.

All of this taken together, confirms the position of Semishin that "the water molecules in the aquo-complex are unequal, that they are arranged in water layers within the internal sphere of the complex, differing by the energy of addition and by the degree of mobility of the proton [5]".

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THERMAL DEPENDENCE OF THE HYDRATION REACTION RATE OF THE METAPHOSPHORIC ACIDS

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The stereochemical theory of Yu. V. Khodakov [1,2] has been confirmed by the example of phosphoric anhydride hydration in the work of Khodakov and Rodionova [3]. The metaphosphoric acid formed upon hydration of phosphoric anhydride was found to be tetrametaphosphoric acid, i.e., an acid of different nature than the trimetaphosphoric acid.

In the present work the temperature function of the hydration reaction rate of trimeta- and of tetrametaphosphate ions, in alkaline and in acid media, was investigated for the purpose of finding a physico-chemical method for the identification of these meta acids, for they do not differ from one another analytically (all of their salts are soluble).

The hydration reaction, both of the trimetaphosphate and of the tetrametaphosphate ion, is evidently monomolecular, but in diluted aqueous solution the quantity of water used for hydrolysis should be neglected, and the concentration of water considered to be constant, then the speed of reaction will be expressed by the first order equation:

$$K = \frac{2.303}{\tau} \log \frac{a}{a-x},$$

where: a − initial concentration;
c = (a − x) − concentration in the moment of τ;
τ − time, in minutes
K − velocity constant.

The characteristic peculiarities of the equation for first order reactions are that the numerical value for the velocity constant does not depend upon choice of units for concentration, and at the same time the half-life does not depend upon the initial concentration, and can appear as the velocity characteristic of such reactions, the same as the constant. The half-life period can be calculated according to the following formula:

$$\tau_{\frac{1}{2}} = \frac{\log 2}{K} = \frac{0.693}{K}.$$

The reaction rate increases rapidly with temperature.

The dependence of reaction rate upon temperature can be expressed by the equation $\log K = B - \frac{A}{T}$, according to which the value, log K, in the function $\frac{1}{T}$ should be graphically expressed by a straight line, while the tangent of the angle of the straight line with the abscissa axis gives the constant A, and the section cut by it on the ordinate axis gives B.

The constant coefficient, B, is the logarithm of the total number of molecular impacts. The coefficient $A = \frac{E}{2.303R} = \frac{E}{4.575}$, where E = activation energy, i.e., that minimum energy which the molecule should possess in order that the impacts be effective.

The reaction should be preceded by a weakening or break-down of the internal bonds of the reacting molecules, without which, regrouping of the atoms is impossible, to lead to the formation of molecules of reaction products.

Ordinarily the mean energy of the molecules is considerably lower than the activation energy, thus the value of the activation energy is determined only by a few co-impacts of the higher energy-containing molecules.

The number of activated molecules able to react increases with increase in temperature.

If the velocity constants are known for different temperatures from experiment, then the activation energy can be computed according to the equation:

$$E = \frac{RT_2T_1}{T_2-T_1}\ 2.303\log\frac{K_2}{K_1}\ .$$

The hydration reaction of the trimeta- and the tetra-metaphosphates prdceed with sufficient speed only in acid or alkaline solution, where they are catalyzed by the H_3O^+ or the OH^- ions. The velocity constant is proportional to the concentration of catalytic ions.

EXPERIMENTAL

Starting materials for execution of the work were sodium trimetaphosphate and tetrametaphosphate.

The trimetaphosphate of sodium was obtained by calcination of the monosubstituted derivative of sodium orthophosphate at a defined temperature rate. The product obtained after calcination was recrystallized and dehydrated in a drying cabinet and over sulfuric acid.

Sodium tetrametaphosphate was prepared by neutralization of a freshly prepared solution of tetrametaphosphoric acid, obtained by dissolving in water the volatile modification of phosphoric anhydride.

The extreme hygroscopicity of the phosphoric anhydride necessitated application, during the work, of a whole series of precautions. In order to obtain pure tetrametaphosphoric acid, the phosphoric anhydride was dissolved in water in small portions, cautiously, to avoid heating up. The acid obtained was titrated, and the whole solution was then neutralized with the calculated quantity of alkali.

The reactions, occurring at the same time, can be expressed by the following equations:

$$P_4O_{10} + 2H_2O = H_4P_4O_{12},$$

$$H_4P_4O_{12} + 4NaOH = Na_4P_4O_{12} + 4H_2O.$$

The sodium tetrametaphosphate solution obtained in this manner could be preserved for a few days' duration.

Procedural Method for Conduction of the Hydration Reaction

The hydration reaction of both sodium trimetaphosphate and tetrametaphosphate was carried out in a glass test tube with a dephlegmator and thermostatic heating with an electric heater.

The thermostatic temperature was supported with the help of a thermoregulator with an accuracy of ± 0.01° C.

Approximately 50 ml of 0.1 N-solution was taken for hydration, to which was added alkali (or acid) in such volume as to maintain in the mixture a concentration 0.1 N with respect to alkali (or acid). After lapse of a given time, from the beginning of heating of the solution, a 5 ml sample was taken which was rapidly cooled and analyzed.

After cooling, the solution of sample taken was neutralized accurately to a pH of 9.2 in the presence of phenolphthalein. An excess of silver nitrate solution was added to the neutral solution for precipitation of the hydration products. Neither trimetaphosphate nor tetrametaphosphate ions precipitate with silver ion, but the hydration products precipitate. The precipitate was filtered off.

1-2 ml of concentrated nitric acid was added to the filtrate to determine the quantity of remaining non-hydrated metaphosphate ions, and the solution was evaporated for 1-1.5 hours on a sand bath (but not to dryness). Upon such lengthy boiling in the presence of the concentrated acid, the m-phosphate ions hydrate fully, and transform into o-phosphate ions.

After cooling, the solution was diluted with water, neutralized to pH 9.2, and the o-phosphate ion precipitated by silver nitrate. At a pH of 9.2 there could only be present in the solution the ions of $HPO_4^{=}$, which, upon reaction with silver ions, form hydronium ions according to the reaction:

$$H_2O + HPO_4^{=} + 3\,Ag^{\cdot} = Ag_3PO_4 + H_3O^{\cdot}\ ,$$

during which the pH of the solution decreases.

The liberated hydronium ions were very accurately titrated with alkali in the presence of phenol red indicator.

From the quantity of alkali used for titration of the hydronium ions, the equivalent concentration of phosphate ion was calculated.

On the basis of the data obtained, kinetic curves were plotted, demonstrating changes in concentration of initial product with time.

The rate constants were then calculated and finally the activation energy of hydration for m-phosphoric acids.

TABLE 1

Hydration of trimetaphosphate in alkaline medium at a temperature of 65°

Time (in min.)	0.0347 N-KOH (ml)	Normality (N) of sample sol.	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0794	100	–
30	7.60	0.0528	66.7	0.0099
65	5.55	0.0387	48.7	0.0111
90	4.92	0.0342	43.0	0.0094
160	2.15	0.0149	18.8	0.0105
			Average K = 0.010	

TABLE 2

Hydration of trimetaphosphate in alkaline medium at a temperature of 75°

Time (in min.)	0.0426 N-KOH (ml)	Normality (N) of sample sol.	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0822	100.0	–
17	6.2	0.0540	65.0	0.024
45	4.4	0.0375	45.5	0.017
68	3.5	0.0300	36.0	0.015
90	2.25	0.0192	23.5	0.016
0	–	0.079	100.0	–
10	8.0	0.067	76.0	0.017
30	5.0	0.426	54.0	0.020
			Average K = 0.022	

TABLE 3

Hydration of trimetaphosphate in alkaline medium at a temperature of 85°

Time (in min.)	0.0347 N-KOH (ml)	Normality (N) of sample sol.	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0788	100.0	–
6	8.20	0.0570	73.0	0.054
22	4.60	0.0320	41.0	0.042
37	2.60	0.0180	26.0	0.040
65	1.20	0.0084	11.0	0.038
			Average K = 0.042	

TABLE 4

Hydration of trimetaphosphate in alkaline medium at a temperature of 90°

Time (in min.)	0.0347 N-KOH (ml)	Normality (N) of sample sol.	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0788	100.0	–
5	4.7	0.0326	42.0	–
18	2.9	0.0199	25.3	0.078
48	0.7	0.0049	6.2	0.077
53	0.2	0.0014	1.8	0.076
			Average K =	0.077

Experimental Results

The results of experiments on the hydration of trimetaphosphate- and tetrametaphosphate-ions, in alkaline and acid media, at various temperatures, are compiled in the following tables and graphs shown below. In graph 1 of the tables, the time of taking of sample from the start of the reaction is indicated. In graph 2 is indicated the number of milliliters of alkali used for titration of the hydronium ions released upon precipitation of the phosphate ions by silver ions in 5 ml of solution. The concentration of phosphate ion is expressed by the normality of the solution and is quoted in graph 3.

In graph 4 is given the percentage of non-hydrated m-phosphate remaining at the moment of sampling.

In graph 5 are quoted the rate constants for a given temperature and the average speed is deduced.

The concentration changes of m-phosphate with time are pictured in Figs.1, 3 and 5, where a curve corresponds for each temperature. On the abscissa axis, time is marked (in minutes), and on the ordinate axis - the percentage of nonhydrated metaphosphate ion remaining.

I. The hydration reaction of trimetaphosphate in alkaline solution was studied at temperatures of 65, 75, 85 and 90°. The alkalinity of the solutions was about 0.1 normal. 25 ml of the solution was taken for reaction.

The results of the experiments, and the calculated rate constants, are cited in Tables1, 2, 3 and 4.

The monomolecularity of the trimetaphosphate hydration reaction was examined by means of the curves of Fig. 1. Good agreement for half-life periods found graphically, with half-life periods calculated according to the formula: $\tau_{\frac{1}{2}} = \frac{\log 2}{K}$, quoted in Table 5, was obtained.

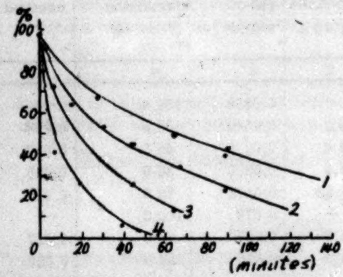

Fig. 1. Hydration reaction of trimetaphosphate in alkaline medium. 1 - at 65°; 2 - at 75°; 3 - at 85°; 4 - at 90°.

TABLE 5

Half-life period for the trimetaphosphate ion in alkaline medium

Temp. (°C)	Rate Constant	$\frac{\log 2}{K}$	Half-life period in minutes	
			Calculated theoretically	Found by curves
65	0.010	$\frac{0.693}{0.010}$	69.3	65
75	0.022	$\frac{0.693}{0.022}$	34.6	38
85	0.042	$\frac{0.693}{0.042}$	18.0	17
90	0.077	$\frac{0.693}{0.077}$	8.0	7

TABLE 6

Relation of rate constant for the trimetaphosphate hydration reaction in alkaline medium to the temperature

T = t + 273°	$\frac{1}{T} \cdot 10^5$	K	log K
1	2	3	4
338	295	0.010	−2.000
348	287	0.022	−1.660
358	280	0.042	−1.370
363	275	0.077	−1.120

Moreover, to confirm the monomolecularity of the hydration reaction, the dependence of the rate constant upon temperature is graphically demonstrated in Fig.2, where the reciprocal of the absolute temperature is indicated on the abscissa axis, and the logarithm of the rate constant on the ordinate axis. The figures required for constructing the graph of temperature dependence of the rate constant, for the hydration reaction of trimetaphosphate in alkaline medium, are cited in Table 6.

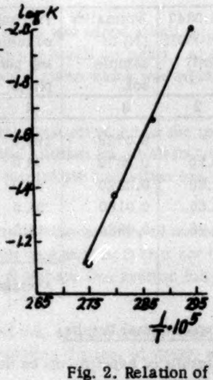

Fig. 2. Relation of rate constant for the trimetaphosphate hydration reaction in alkaline medium to the temperature

The straight line produced indicates that the constants found from experiment are correct, since the points corresponding to their values are well arranged on the straight line.

Using the rate constants for various temperatures, according to the formula $E = \frac{RT_1T_2}{T_2 - T_1} \; 2.303 \log \frac{K_2}{K_1}$, the activation energy for the

TABLE 7

Hydration of tetrametaphosphate in alkaline medium at a temperature of 75°

Time (in min.)	0.0434 N-KOH (ml)	Normality of the sample solution	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0478	100.0	–
70	4.85	0.0423	88	0.0016
105	4.5	0.0390	82	0.0018
145	4.15	0.0362	76	0.0018
215	4.1	0.0350	73	0.0014
315	3.9	0.0336	70	0.0011

Average K = 0.0015

TABLE 8

Hydration of tetrametaphosphate in alkaline medium at a temperature of 85°

Time (in min.)	0.0434 N-KOH (ml)	Normality of sample solution	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0478	100.0	–
80	4.40	0.0384	80.5	0.0027
120	3.83	0.0334	69.0	0.0030
220	2.86	0.0248	52.0	0.0029
240	2.75	0.0238	50.0	0.0029
300	2.50	0.0216	45.0	0.0026

Average K =0.0029

TABLE 9

Hydration of tetrametaphosphate in alkaline medium at a temperature of 90°

Time (in min.)	0.0584 N-KOH (ml)	Normality of sample solution	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	7.7	0.0900	100	–
55	6.0	0.0705	78	0.0048
85	5.3	0.0601	67	0.0047
140	4.0	0.0464	53	0.0048
180	3.15	0.0370	41	0.0048

Average K = 0.0048

TABLE 10

Hydration of tetrametaphosphate in alkaline medium at a temperature of 95°

Time (in min.)	0.043 N-KOH (ml)	Normality of sample solution	Percentage of remaining phosphate	Rate constant
1	2	3	4	5
0	–	0.0478	100	–
60	3.0	0.0261	55.0	0.010
127	1.5	0.0126	26.5	0.010
187	0.83	0.0072	15.2	0.010
240	0.42	0.0036	7.6	0.010

Average K =0.010

TABLE 11

Hydration of tetrametaphosphate in alkaline medium at a temperature of 100°

Time (in min.)	0.0434 N-KOH (ml)	Normality of sample solution	Percentage of remaining phosphate	Rate constant
0	–	0.0975	100	–
18	8.3	0.0710	73	0.016
60	3.6	0.0410	42	0.015
90	3.1	0.0268	27	0.016

Average K = 0.016

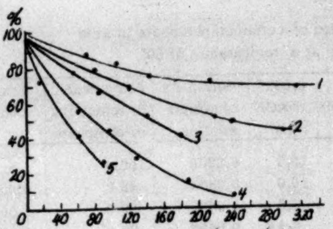

Fig. 3. Hydration reaction of tetrametaphosphate in alkaline medium. 1. at 75°; 2. at 85°; 3. at 90°; 4. at 95°; 5. at 100°.

trimetaphosphate hydration reaction in alkaline medium was calculated, the average value of which is equal to 20,000 calories.

II. The tetrametaphosphate-ion hydration reaction in alkaline medium was carried out at temperatures of 75, 85, 90, 95 and 100° in a manner similar to that described for the reactions with tremetaphosphate. The alkalinity of the solutions was approximately 0.1 N.

TABLE 12

Half-life periods of the tetrametaphosphate in alkaline medium

Temp (°C)	$\frac{\log 2}{K}$	Half-life period in minutes	
		Calculated theoretically	Found by the curves
75	$\frac{0.693}{0.0015}$	560	–
85	$\frac{0.693}{0.0029}$	240	240
90	$\frac{0.693}{0.0048}$	145	143
95	$\frac{0.693}{0.010}$	70	80
100	$\frac{0.693}{0.016}$	43	43

TABLE 13

Dependence of rate constant for the tetrametaphosphate hydration reaction in alkaline medium to the temperature

T = t + 273°	$\frac{1}{T}\cdot 10^5$	K	log K
348	287	0.0015	–2.903
358	279	0.0029	–2.637
363	276	0.0048	–2.320
368	272	0.010	–1.993
373	268	0.0160	–1.793

25 ml of solution was taken for reaction.

Results of the experiments are quoted in tables 7,8,9,10 and 11, and in the curves of Fig.3, where a curve corresponds to each temperature.

Examination of the monomolecularity of the tetrametaphosphate hydration reaction in alkaline medium has demonstrated a satisfactory conformity of the half-life period values, found graphically by the curves in Fig. 3, and calculated theoretically according to the formula $\tau_{1/2} = \frac{\log 2}{K}$, the values of which are quoted in Table 12.

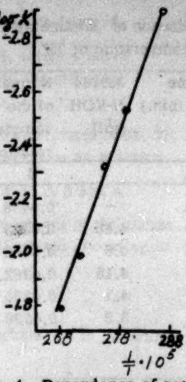

Fig. 4. Dependence of rate constant for the tetrametaphosphate hydration reaction in alkaline medium to the temperature.

In Table 13 are quoted figures for the structure of Fig.4, showing the relation of the rate constant to temperature.

The resulting straight line indicates that the constants found are accurate, because the points corresponding to their values lie on a straight line.

Utilizing the rate constants found at different temperatures, the activation energy of the tetrametaphosphate hydration reaction in alkaline medium was calculated to be equal, on the average, to 26,000 cal.

TABLE 14

Hydration of tetrametaphosphate in acid medium at a temperature of 60°

Time (in min.)	0.0417 N-KOH (ml)	Normality of sample solution	Percentage of remaining m-phosphate	Rate constant
0	10.2	0.0850	100.0	–
25	10.0	0.0834	98.0	0.00093
45	7.8	0.0793	90.0	0.0018
90	8.4•	0.0695	82.0	0.0018
150	11.8••	0.0654	76.5	0.00178
			Average K =	0.0018

TABLE 15

Hydration of tetrametaphosphate in acid medium at a temperature of 65°

Time (in min.)	0.0474 N-KOH (ml)	Normality of sample solution	Percentage of remaining m-phosphate	Rate constant
0	7.8	0.0740	100	–
25	6.8	0.0645	87	0.0056
100	4.6	0.0438	59	0.0055
165	5.0•••	0.0304	45	0.0054
			Average K =	0.0055

• 10 ml taken for analysis

•• 15 ml taken for analysis

••• 10 ml taken for analysis

TABLE 16

Hydration of tetrametaphosphate in acid medium at a temperature of 75°

Time (in min.)	0.0417 N-NaOH (ml)	Normality of sample solution	Percentage of remaining m-phosphate	Rate constant
0	9.9	0.105	100	–
10	9.7	0.0940	89.0	0.0115
30	8.7	0.0725	67.5	0.0130
40	7.8	0.0650	62.0	0.0120
55	6.5	0.0523	49.5	0.0120
75	5.5	0.0458	43.5	0.0111
			Average K =	0.012

TABLE 17

Hydration of tetrametaphosphate in acid medium at a temperature of 85°

Time (in min.)	0.0417 N-NaOH (ml)	Normality of sample solution	Percentage of remaining m-phosphate	Rate constant
0	10.2	0.0850	100.0	–
20	5	0.0417	49.0	0.035
32	3.3	0.0275	32.4	0.035
50	1.9	0.0158	18.6	0.034
			Average K =	0.034

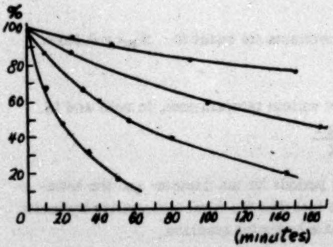

Fig. 5. Hydration reaction of tetrametaphosphate in acid medium
1. at 60°; 2. at 65°; 3. at 75°; 4. at 85°.

TABLE 18

Semidecomposition periods of tetrametaphosphate in acid medium

Temp. (°C)	log 2 / K	Half-life period (in min.)	
		Calculated theoretically	Found from curves
60	$\frac{0.693}{0.0018}$	385	–
65	$\frac{0.693}{0.0055}$	128	140.0
75	$\frac{0.693}{0.012}$	57.7	57.5
85	$\frac{0.693}{0.035}$	19.8	20.0

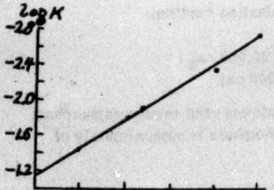

Fig. 6. Dependence of rate constant, for the hydration reaction of tetrametaphosphate in acid medium upon temperature

III. The hydration reaction for the tetrametaphosphate ion in acid medium was carried out in the same manner as described above. The acidity of the medium was approximately 0.15 N. 30 ml of solution was taken for reaction.

Results of the experiments conducted in acid medium, at temperatures of 60,65,75 and 85°, are compiled in tables 14,15, 16,17, and are graphically represented by the curves in Fig. 5.

TABLE 19

Temperature dependence of rate constant for the hydration reaction of tetrametaphosphate in acid medium

T=t + 273°	$\frac{1}{T}\cdot 10^4$	K	log K
358	28.0	0.0018	−1.46
348	28.7	0.0055	−1.92
338	29.5	0.0120	−2.26
333	30.0	0.0340	−2.75

The theoretically calculated half-life periods for tetrametaphosphate-ion in acid medium at various temperatures, which are quoted in Table 18, have shown good agreement with the half-life periods found from the curves of Fig. 5.

To confirm the monomolecularity of the tetrametaphosphate hydration reaction in acid medium, the dependence of the rate constants upon temperature in acid medium has been graphically demonstrated (Fig.6). The numerical data for construction of Fig. 6 are quoted in Table 19.

The activation energy for the hydration reaction of tetrametaphosphate in acid medium was calculated, utilizing the values for the rate constants at various temperatures, according to the formula

$$E = \frac{RT_1T_2}{T_2 - T_1} \; 2.303 \log \frac{K_2}{K_1},$$

the average value for which is 25,300 cal.

SUMMARY

1. In order to confirm the theory of Yu. V. Khodakov about the hydration of phosphoric anhydride and phosphoric acids, the hydration reaction rates for trimeta- and tetrametaphosphate-ions were studied in alkaline and in acid media, at various temperatures, and from the experimental data the rate constants of these reactions were calculated.

For the hydration of trimetaphosphate in alkaline medium the constants are equal to: $K_{65°} = 0.010$; $K_{75°} = 0.022$; $K_{85°} = 0.042$; $K_{90°} = 0.077$.

For the hydration of tetrametaphosphate in alkaline medium the constants are equal to: $K_{75°} = 0.0015$; $K_{85°} = 0.0029$; $K_{90°} = 0.0048$; $K_{95°} = 0.010$; $K_{100°} = 0.016$.

For the hydration of tetrametaphosphate in acid medium the constants are equal to: $K_{55°} = 0.0018$; $K_{65°} = 0.0055$; $K_{75°} = 0.012$; $K_{85°} = 0.034$.

2. The half-life periods of trimeta- and tetrametaphosphates at various temperatures, in acid and in alkaline media, were calculated according to the formula $\tau_{1/2} = \frac{\log 2}{K}$.

3. A comparison of the rate constants, as well as the half-life periods for the trimeta- and the tetrametaphosphates, under the same conditions (t° and pH), confirmed the fact that the trimetaphosphate hydration reaction goes approximately 16 times faster than the tetrametaphosphate hydration reaction.

4. A comparison of the rate constants for the hydration reaction of tetrametaphosphate in alkaline and in acid media has indicated that, in acid medium, the reaction goes approximately 12 times faster than in alkaline medium for the same normality of the solutions.

5. The following were calculated from the experimental data:

1) The activation energy for the trimetaphosphate hydration reaction in alkaline medium: E = 20,000 cal.;
2) the activation energy of tetrametaphosphate in alkaline medium: E = 26,000 cal.;
3) the activation energy of tetrametaphosphate in acid medium: E = 25,300 cal.

6. As a result of the comparison of the activation energy values for the trimeta- and tetrametaphosphate at various pH's, it was determined that the activation energy for the given metaphosphate is approximately of one and the same order.

7. The stable value of the constants for various moments of time indicates that the hydration reactions of the trimeta- and the tetrameta-phosphates, in alkaline as well as acid medium, are found to be of the first order. Moreover, the half-life period of the trimeta- and tetrameta-phosphates does not depend upon the initial concentration, which also confirms the monomolecularity of the hydration reaction for trimeta- and tetrameta-phosphate, both in alkaline and in acid media.

8. The dependence of the hyration reaction rate of trimeta- and tetrameta-phosphates upon temperature was found, which is graphically represented by a straight line.

In conclusion the author wishes to express his great indebtedness to Professor Yu. V. Khodakov for the interesting theme proposed and for the series of valuable directions in the work.

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Chair of Chemistry, S. Ordzhonikidze, [illegible]
Moscow Aviation Institute
Awarded the Order of Lenin

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* See Consultants Bureau English translation page 1401

POLAROGRAPHIC ANALYSIS OF CADMIUM IODIDE COMPLEXES IN WATER–ALCOHOL SOLVENT

A.L.Markman and Ya.I.Turyan

In the preceding paper [1] it was demonstrated that the half-wave potential both of the simple and of the complex ions of cadmium, lead and thallium change in water–alcohol solvent with variation in the alcohol content. A particularly strong displacement of the half-wave potential was observed for cadmium in KI. Simultaneously with increase in ethanol content, the half-wave potential was displaced toward the negative values, which, as was explained by the authors in the same article, is the result of a considerable decrease for the dissociation constant of the complex cadmium ion, in proportion to the addition of alcohol.

The present work is concerned with the determination of the composition of the iodide complexes of cadmium, and their dissociation constants in water–alcohol solvent of varied alcohol content. As far as is known, the given problem has not been discussed at all thoroughly in the literature. It should be noted that in general the effect of the anhydrous solvent upon the composition and the dissociation constant of the complex ion has hardly been studied. At the same time there is no reflection to be cast upon the values of similar investigations from the viewpoint of the theory of solutions and of analytical chemistry.

The authors decided to apply the polarographic method for determining in a given solvent the content of cadmium iodide complexes and their dissociation constants, based upon the reversibility of the reaction of electroreduction of cadmium at the dropping mercury electrode from water–alcohol solution, which was determined by the authors [1]. The polarographic behavior of cadmium iodide complexes in aqueous solution has been studied in detail by Stromberg and Bykov [2].

EXPERIMENTAL

The iodide complexes of cadmium were investigated in 20, 45 and 65% (by volume) ethanol. The initial solutions contained $1 \cdot 10^{-4}$ M $Cd(NO_3)_2$ and KI; the concentration of the latter was changing from 0.1 to 0.9 M (by 0.2 units). In addition, gelatin (0.01%) was added to all solutions for depression of the maxima. The temperature for the measurements was 25 ± 0.2°. The characteristic of the capillary was: $m^{2/3}\tau^{1/6} = 1.50$ mg$^{2/3}$ sec.$^{-1/2}$ (at 0.8-0.9 V, relative to the calomel-saturated electrode). This characteristic was practically independent of the alcohol content in the solution. A more detailed method of experimental procedure is described in the preceding work [1].

The results obtained for cadmium polarography in water–alcohol solvent, with variable concentrations of KI and of alcohol, are represented in Table 1 (diffusion currents) and in Table 2 (half-wave potentials relative to the calomel-saturated electrode).

TABLE 1

Diffusion current in microamperes

C_2H_5OH (%)	Concentration of KI (moles/liter)				
	0.1	0.3	0.5	0.7	0.9
20	5.05	5.02	5.08	5.12	5.08
45	4.09	4.16	4.29	4.32	4.46
65	4.07	4.09	4.22	4.26	4.46

TABLE 2

Half-wave potentials (in V)

C_2H_5OH (%)	Concentration of KI (moles/liter)				
	0.1	0.3	0.5	0.7	0.9
20	−0.647	−0.698	−0.729	−0.747	−0.763
45	−0.673	−0.725	−0.751	−0.764	−0.784
65	−0.705	−0.750	−0.777	−0.794	−0.815

The half-wave potentials were found on the graph (the potential being a function of $\log \frac{i}{i_d - i}$ after corrections were made for the ohm resistance of the electrolyte and for the non-standard potential of the calomel-saturated electrode [1]. An example of such a graph is represented for 45% alcohol in Figure 1. The angular coefficients of the straight lines (Figure 1) are equal to 0.030 for all concentrations of KI, which attest to the reversibility of the electroreduction process, foi the valence of the metallic ion, $\underline{n} = 2$.

Based upon the work of A. I. Brodsky [3], the authors disregarded the very insignificant effect of diffusion potentials upon measurements of the magnitude of the half-wave potentials.

The coordination numbers of the complex ions were found according to the following equation [4]:

$$\frac{d(\pi_{1/2})_C}{d \log C_x f_x} = -p \frac{0.059}{n}, \qquad (1)$$

where $(\pi_{1/2})_C$ is the half-wave potential of the complex ion, C_X and f_X, correspondingly the concentration and the coefficient of the complexing agent activity, $\underline{p}$ is the coordination number of the complex ion, and $\underline{n}$ is the valence of the metallic ion.

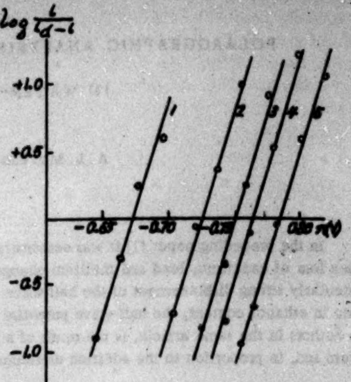

Fig. 1. Determination of the half-wave potential of cadmium in water–alcohol solution of KI. Alcohol concentration 45% (by vol.). KI concentration: 1) 0.1 M; 2) 0.3 M; 3) 0.5 M; 4) 0.7 M; 5) 0.9 M.

It should be noted that derivation of Equation (1) allows: first, invariability of the value of the activity coefficient for the complex ion (f_C) with variation in the concentration of the complexing agent (C_X), which does not correspond to reality, and secondly, invariability of the diffusion current constant (k_C) with variation in the concentration of the complexing agent (C_X), which is occasionally not maintained in practice. For example, in our experiments at alcohol contents of 45% and of 65%, the diffusion current somehow was increasing* with an increase in KI concentration (Table 1), in accordance with the diffusion current constant. Nevertheless, disregarding the minor variations of f_C and k_C with change in C_X in the derivation of Equation (1), the authors do not include the error in determination of the coordination number, $\underline{p}$, as already noted by Stromberg and Bykov [2], since the latter is a whole number, which allows for rounding off the calculation result. For the same reason Kolthof and Lingane [4] recommend, without detriment to the accuracy of the calculation, substitution for the complexing agent activity ($C_X f_X$), the value of the complexing agent concentration (C_X) in Equation (1). In our calculations of the coordination number according to Equation (1), the activity of the complexing agent (KI) in aqueous solution [5] was used instead of the activity of the complexing agent ($C_X f_X$) in water–alcohol solution.

The value of the derivative $\frac{d(\pi_{1/2})_C}{d \log C_x f_x}$ in Equation (1) is shown graphically from Figure 2. On the ordinate axis are placed the half-wave potentials $(\pi_{1/2})_C$ (Table 2), and on the abscissa the logarithm of the complexing agent activity. As can be seen from Figure 2, for all three solvents, the sought-for correlation $(\pi_{1/2})_C$ depending upon the $\log C_X f_X$ is represented by a straight line, which indicates the stability of the composition of the complex ion within the investigated interval of complexing agent concentration. On the basis of the angular coefficients of the straight lines $\frac{d(\pi_{1/2})_C}{d \log C_x f_x}$ obtained from Figure 2, the corresponding coordination numbers were calculated according to Equation (1), which proved to be the same: the same coordination number is obtained for all solutions; $\underline{p} = 4$,

TABLE 3

Half-wave potentials and the values of diffusion current $1 \cdot 10^{-3}$ M $Cd(NO_3)_2$ in water–alcohol solutions of 0.1 mm NH_4NO_3

C_2H_5OH (%)	$(\pi_{1/2})_s$ (V)	$(i_d)_s$ (cal.)
20	−0.571	4.62
45	−0.560	3.83
65	−0.549	3.53

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* Taking into account the above-noted reversibility of the electroreduction process, the variation in diffusion current flow with variation in KI concentration can be explained in the given case by the variability of the diffusion coefficient for the complex ion.

and consequently the composition of the complex ion is: $[CdI_4]^{2-}$. According to the data of Stromberg and Bykov [2], the same composition for the cadmium complex ion was observed in aqueous solutions of KI. Thus, the authors have come to the conclusion that substitution of water for water–alcohol does not affect the composition of cadmium iodide complex.

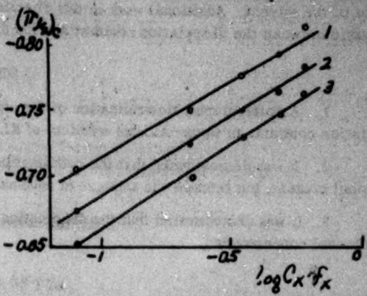

Fig. 2. Potentials of cadmium half-wave in water–alcohol solution, depending upon the log of the KI activity. 1) 65% CH_2H_5OH; 2) 45% C_2H_5OH; 3) 20% C_2H_5OH.

The calculated constants for the dissociation of the complex ion $[CdI_4]^{2-}$ were derived from the equation quoted from Kolthof and Lingane [4]:

$$(\pi_{1/2})_C-(\pi_{1/2})_S=\frac{0.059}{n}\log K_C-\frac{0.059}{n}\log\frac{f_s k_C}{f_C k_S}-\frac{0.059}{n}p\log C_x f_x \qquad (2)$$

where of the new values: $(\pi_{1/2})_S$ is the half-wave potential of the simple metallic ion; K_C is the dissociation constant for the complex ion; k_c and k_s are the diffusion current constants, respectively, of the complex and of the simple metal ion; f_C and f_S are the activity coefficients, respectively, of the complex and of the simple metal ion.

In the preceding article [1], it was indicated that in water–alcohol solutions of $KNO_3(NH_4NO_3)$ cadmium does not form complex ions with the neutral electrolyte. Thus, polarography of cadmium in given solutions offers the possibility of obtaining values of $(\pi_{1/2})_S$ and k_S, which are essential for calculating the dissociation constant of the complex ion (K_C) according to Equation (2). We have utilized the values obtained by us [1] for 0.1 M NH_4NO_3. Their values are quoted in Table 3 (instead of k_S in Table 3, the proportional k_S values of the diffusion current $(i_d)_S$ are contained). The values $(\pi_{1/2})_C$ and k_C were also taken for 0.1 M KI concentration (Tables 1 and 2). Because of $\frac{k_C}{k_S}=\frac{(i_d)_C}{(i_d)_S}$, then instead of $\frac{k_C}{k_S}$ calculations were made for the diffusion currents $\frac{(i_d)_C}{(i_d)_S}$. The relation of the activity coefficients $\frac{f_S}{f_C}$ was taken as equal to unity, because the charges of both the simple and the complex ions, and also the ionic strengths of the solutions, are the same.

TABLE 4

Dissociation constants of the cadmium complex-ion in water–alcohol solutions of KI

C_2H_5OH (%)	0	20	45	65
K_C.	$1.2\cdot10^{-6}$	$0.91\cdot10^{-7}$	$3.3\cdot10^{-9}$	$0.71\cdot10^{-10}$

For calculation of the dissociation constant for the complex ion, the important value, $C_x f_x$, should be calculated as accurately as possible. We did not find in the literature any experimental data on the determination of activity coefficients for KI in water–alcohol solution. The values of these coefficients (f_x) for 0.1 M KI solutions with varied content of alcohol were calculated according to the known formula of Debye-Hückel:

$$\log f_x=\frac{250\cdot n_i^2\cdot D^{-\frac{3}{2}}\sqrt{I}}{1+2.06\cdot b_i\cdot D^{-\frac{1}{2}}\sqrt{I}}, \qquad \log f_x=\frac{250\cdot n_i^2\cdot D^{-\frac{3}{2}}\sqrt{I}}{1+2.06\cdot b_i\cdot D^{-\frac{1}{2}}\sqrt{I}} \qquad (3)$$

which is applicable for moderately concentrated solutions. In this formula $\underline{D}$ is the dielectric constant of the solvent (the value, $\underline{D}$, at various alcohol contents, is quoted in our previous work [1]); b_i is the constant, which, for KI, as comparison of the calculated and the experimental activity coefficients for KI in aqueous solutions shows, is equal to 5 A; $\underline{I}$ is the ionic strength of the solution; n_i is the ionic valency. After substitution in Equation (2) of the corresponding values $(\pi_{1/2})_C$, $(\pi_{1/2})_S$, $\frac{k_C}{k_S}$, $\underline{D}$, C_x and f_x, the dissociation constants of the complex ions were calculated. The results of these calculations are summarized in Table 4. For aqueous solution, the value K_C was taken from the work of Stromberg and Bykov [2].

As can be seen from Table 4, with an increase in alcohol content there occurs a sharp decrease in the dissociation constant of the complex ion $[CdI_4]^{2-}$. Thus, for 65% alcohol, the dissociation constant is approximately 10-20 thousand times smaller than the dissociation constant in aqueous solution. It is evident that the observed decrease in dissociation constant for the complex ion is first of all correlated with a decrease in the dielectric constant of the solvent. Additional work in this direction should make it possible to determine the qualitative relationship between the dissociation constant and the dielectric constant of the solvent.

SUMMARY

1. A polarographic determination of the composition of the cadmium iodide complexes and their dissociation constants in water–alcohol solutions of KI, with varied alcohol content, was carried out.

2. It was demonstrated that the coordination number of the complex ion does not change with change in alcohol content, but remains the same as in aqueous solutions.

3. It was demonstrated that the dissociation constant of the complex ion decreases sharply with an increase in alcohol concentration.

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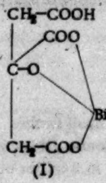
Central Asian Polytechnical Institute

FORMATION OF BASIC AND ACID BISMUTH CITRATES UPON THERMAL DECOMPOSITION OF AMMONIUM CITROBISMUTHATE

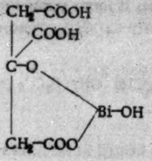
N. M. Turkevich

The simplest bismuth citrate $C_6H_5O_7Bi \cdot H_2O$ exhibits acid properties and forms complex salts with alkali which are soluble in water. Many authors [1-4] have studied its structure, and have most frequently ascribed to it a formula with one or two carboxyl groups (I), (II), (III), (IV):

(V)



(I)



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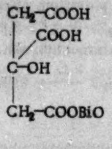

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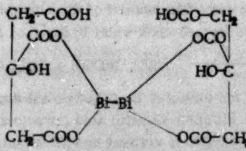
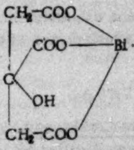


(IV)

On the basis of certain properties (the presence of coordinately-bound water which passes off very slowly, even at 105°, the easy replacement of this water by ammonia molecules with the formation of ammoniate, and others) the author [5] assigns the structure of aquo compound (V) to bismuth citrate – abbreviated as $CiBi \cdot OH_2$, where Ci denotes the citric acid residue. Bismuth citrate forms [6], upon solution in ammonia, a salt of the general formula $(3NH_4OH \cdot 2BiCi \cdot 3H_2O)_n$, soluble in water without hydrolysis. The determination of the number n with the help of the molecular weight is difficult because ammonium citrobismuthate does not dissolve in organic solvents, and, in water, is exposed not only to electrolytic dissociation, but also to partial depolymerization (to the point of monomers – as regards the number of bismuth atoms in the ion). Deduction can be made, on the assumption of various transformations of ammonium citrobismuthate, that n is equal to a minimum of 2, and thus, for simplicity, we shall use for it the formula of the tetramer $6NH_3 \cdot 4BiCi \cdot 12H_2O$.



(V)

The monomeric ammonium salt of the structure $(CiBi \cdot OH)NH_4$, the anhydride of which the author [6] has isolated in the form of an ammoniate, $CiBi \cdot NH_3$, has not been described up to the present time. There appear in the literature short notices about the three basic or acid citrates. Bismutho-dicitric acid $BiCi \cdot CiH_3 \cdot xH_2O$ is obtained [7] by reaction of citric acid with bismuth nitrate in glycerine medium. The basic citrate – $BiCi \cdot 4Bi(OH)_3$, is obtained [8] by heating an ammoniacal solution of BiCi, and the salt $Ci(BiO)_2Na$ is formed [4] by dissolving BiCi in a solution of NaOH.

The author has found that upon heating ammonium citrobismuthate, not only is water expelled, but also ammonia, and different acidic and basic salts are formed. While boiling with benzene, 6 molecules of water are expelled and an insignificant amount of ammonia, with the formation of $6NH_3 \cdot 4BiCi \cdot 6H_2O$. Further heating of the sample dehydrated in this way at 105° leads to gradual loss of the ammonia molecule. 1 mole of ammonia is volatilized within 9 hours, but the product $5NH_3 \cdot 4BiCi \cdot 6H_2O$ remains soluble in water, and 1 more mole of ammonia and 1 mole of water are volatilized during 32 hours, forming a water-insoluble substance $4NH_3 \cdot 4BiCi \cdot 5H_2O$. From the aqueous solution $5NH_3 \cdot 4BiCi \cdot 6H_2O$ barium chloride precipitates monomeric barium citrobismuthate $Ba(CiBi \cdot OH)_2 \cdot 5H_2O$. The substance $4NH_3 \cdot 4BiCi \cdot 5H_2O$ hydrolyzes easily in water and alkali. Upon reaction with water, there occurs formation of basic bismuth citrate and the ammonium salt of acid bismuth citrate, according to the equation:

$$4NH_3 \cdot 4BiCi \cdot 5H_2O \longrightarrow BiCi \cdot BiOOH + NH_4OH \cdot (NH_4)_3Ci \cdot 2BiCi \cdot 2H_2O.$$

Dibismuth-monocitrate $BiCi \cdot BiOOH$ (or structurally: $HO \cdot Bi = Ci–BiO$) is entirely devoid of acid properties. With the ammonium and potassium citrates it forms water-soluble complex salts. From an aqueous solution of the ammonium salt $[NH_4]_2Ci–Bi = Ci–Bi[OH]–Ci[NH_4]_2$, representing the salt of dibismuth-tricitrate, alcohol precipitates the monomeric ammonium salt:

$$NH_4OH \cdot (NH_4)_3Ci \cdot 2BiCi \cdot 2H_2O \longrightarrow 2NH_4(CiBi \cdot OH) \cdot H_2O + (NH_4)_2HCi,$$

difficultly soluble in water.

The initial ammonium citrobismuthate, when heated at 50°, loses 2 moles of water, and upon further heating at 80° (for 12 hours) five more moles of water, and only an insignificant amount of ammonia. Subsequent heating of the sample at 105° (for 24 hours) leads to volatilization of 3 more moles of water and to 3 moles of ammonia, with the formation of a water-insoluble product of the abbreviated formula $3NH_3 \cdot 4BiCi \cdot 2H_2O$. The basic citrate and the ammonium salt are formed upon water hydrolysis, according to the equation:

$$3NH_3 \cdot 4BiCi \cdot 2H_2O + 2H_2O \longrightarrow 2BiCi \cdot BiOOH + (NH_4)_3Ci \cdot BiCi \cdot H_2O.$$

It follows from a comparison of the formulas that the two substances obtained are the salts of the simplest acid bismuth citrate $BiCi \cdot CiH_3$, i.e. the bismutho-dicitric acid (structurally: $H_3Ci–Bi=CiH$). The dibismuth salt of bismutho-dicitric acid $HO \cdot Bi=Ci–Bi=Ci–BiO$ is entirely devoid of acid properties. Its very great solubility in solutions of Seignette's salt excludes the possibility of the presence of bismuth hydroxide, or the ammoniate of bismuth citrate, in the form of impurities. The ammonium salt of bismutho-dicitric acid can be represented structurally by the abbreviation: $(NH_4)_2Ci–Bi=CiNH_4$.

Further heating of ammonium citrobismuthate at 130° leads to volatilization of 1 more mole of ammonia. Upon hydrolysis of the obtained product by water, there is obtained more than 88% dibismuth salt of bismutho-dicitric acid.

The basic bismuth citrates (dibismuth-monocitrate and tribismuth-dicitrate) are obtained by thermal decomposition of ammonium citrobismuthate; they possess a high degree of purity, and only in rare cases is contamination by ammoniates (up to 0.4% N).

EXPERIMENTAL

Elimination of 1 Mole of Ammonia from Ammonium Citrobismuthate. 10 g of ammonium citrobismuthate was boiled with benzene for 18 hours, and the volume of water distilled off was determined by a volumetric procedure, according to the method of Diene and Stark. The volume of water measured – 0.54 ml – corresponded to the loss of 6 moles of H_2O (5.4% water instead of the theoretical 5.66%).

303.4 mg substance: 9.9 ml 0.1 N HCl. Found %: N 4.57. $6NH_3 \cdot 4BiCi \cdot 6H_2O$. Calculated %: N 4.66.

The dehydrated substance was soluble in water and in ammonia solutions. 12 g of the dehydrated sample was further heated for 9 hours at 105° to the elimination of 1 mole of ammonia. The heating time was determined in a preliminary way on a small quantity of the sample. A slight yellowing of the sample was observed during the process.

266.8 mg substance: 7.2 ml 0.1 N HCl. Found %: N 3.78. $5NH_3 \cdot 4BiCi \cdot 6H_2O$. Calculated %: N 3.92.

Barium Citrobismuthate. 9.38 g of the latter sample was mixed with 100 ml of water and then heated to boiling. The sample dissolved almost completely, but very slowly. The insoluble sediment (0.12 g – 1.3%) was centrifuged off and washed with water, and it represented (on the basis of analysis and properties) the basic bismuth citrate OBi–Ci=Bi · OH. 100 ml of 10% barium chloride solution was added to the filtrate, heated to boiling. After being allowed to stand, the white insoluble precipitate was centrifuged off and washed with water to the disappearance of a chloride reaction. After washing with alcohol, the sample was air-dried.

227.7 mg substance: 40.9 mg CO_2; 111.1 mg H_2O. 200.5 mg substance: 43.8 mg $BaSO_4$; 115.0 mg $BiPO_4$. Found %: C 13.32; H 2.01; Bi 39.44; Ba 12.86. $C_{12}H_{22}O_{21}Bi_2Ba$. Calculated %: C 13.62; H 2.10; Bi 39.52; Ba 12.99.

Monomeric barium citrobismuthate appeared to be a microcrystalline substance, insoluble in water, alcohol and ether, and soluble in an ammoniacal solution of ammonium citrate. In ammonia it underwent hydrolysis.

Elimination of 2 Moles of Ammonia from Ammonium Citrobismuthate. Ammonium citrobismuthate, dehydrated, dehydrated by boiling in benzene, was heated for 32 hours at 105°. The substance after 12 hours of heating acquired a light yellow-green color. The product obtained was insoluble in water and soluble in ammonia and in ammoniacal solution of ammonium citrate.

408.4 mg substance: 8.4 ml 0.1 N HCl. 267.4 mg substance: 142.6 mg Bi_2O_3. Found %: N 2.88; Bi 47.83. $4NH_3 \cdot 4BiCi \cdot 5H_2O$. Calculated %: N 3.20; Bi 47.76.

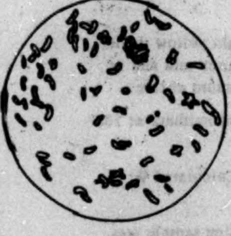


Fig. 1. Monomeric ammonium citrobismuthate X678.

Dibismuth-monocitrate and the Ammonium Salt of Dibismuth-tricitrate. 8.8 g of the preceding product was finely ground in a mortar with water and was mixed for half an hour with 250 ml of water. After 24 hours of standing the mixture was filtered, and the white precipitate obtained was washed with water, alcohol, and dried at 105°. 3.3 g of the water-insoluble, microcrystalline basic bismuth citrate BiCi · BiOOH was obtained. The sample was insoluble in ammonia, but soluble in an ammoniacal solution of ammonium citrate.

187.4 mg substance: 136.8 mg Bi_2O_3. 54.3 mg substance: 22.3 mg CO_2; 5.3 mg H_2O. Found %: Bi 65.48; C 11.20; H 1.09. $C_6H_6O_9Bi_2$. Calculated %: Bi 65.30; C 11.26; H 0.95.

The aqueous solution was steamed off on a water bath after filtration of the basic bismuth citrate, and dried at 105° (for 6 hours).

199.9 mg substance: 7.2 ml 0.1 N HCl. 185.9 mg substance: 77.9 mg Bi_2O_3. Found %: N 5.05; Bi 37.59. $NH_4OH \cdot (NH_4)_2Ci \cdot 2BiCi \cdot 2H_2O$. Calculated %: N 5.05; Bi 37.63.

Ammonium Monohydroxycitrobismuthate. Four times the quantity of alcohol was added to a 2% aqueous solution of ammonium dibismuth-tricitrate. After a month and a half of standing, the precipitate was centrifuged off, washed with alcohol and dried at room temperature in a vacuum-dessicator. The white substance obtained (Figure 1) was very difficultly soluble in water, but soluble in an ammoniacal solution of ammonium citrate. The sample dissolved in ammonia, but hydrolysis occurred upon heating.

58.3 mg substance: 33.4 mg CO_2; 14.5 mg H_2O. 145.7 mg substance: 3.4 ml 0.1 N HCl. 120.6 mg substance: 61.2 mg Bi_2O_3. Found %: C 15.63; H 2.78; N 3.27; Bi 45.52. $(C_6H_5O_7Bi \cdot OH)NH_4 \cdot 1.5H_2O$. Calculated %: C 15.66; H 2.85; N 3.04; Bi 45.42.

Elimination of 3 Moles of Ammonia from Ammonium Citrobismuthate. 3.3637 g of ammonium citrobismuthate was dried at 50°. After 10 hours of drying, the weight was practically unchanged. Loss in weight was 59.9 mg, which corresponds to 1.9 moles of water. Upon further heating, at 80°, the loss in weight ceased almost completely after 12 hours, corresponding to 5 moles of water.

558.7 mg substance: 16.9 ml 0.1 N HCl. Found %: N 4.24. $6NH_3 \cdot 4BiCi \cdot 5H_2O$. Calculated %: N 4.71.

Additional heating was conducted at 105°. After two hours, loss in weight became insignificant. The results of heating at 50, 80 and 105° are represented in Fig. 2.

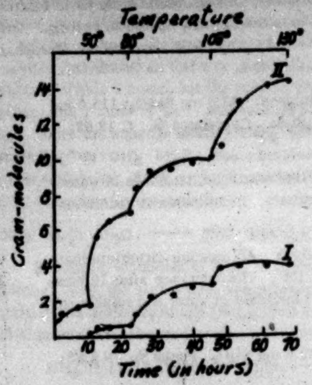


Fig. 2. Heating of Ammonium Citrobismuthate. I) volatilization of ammonia, II) volatilization of water.

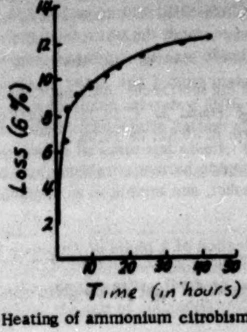


Fig. 3. Heating of ammonium citrobismuthate at 105°

279.7 mg substance: 4.9 ml 0.1 N HCl. Found %: N 2.46. $3NH_3 \cdot 4BiCi \cdot 2H_2O$. Calculated %: N 2.50.

The product obtained had a light yellow shade, insoluble in water, soluble in ammonia and in ammoniacal solution of ammonium citrate.

An identical product was obtained upon direct heating of original ammonium citrobismuthate at 105° for 42 hours (Figure 3).

521.4 mg substance: 9.7 ml 0.1 N HCl. Found %: N 2.61. $3NH_3 \cdot 4BiCi \cdot 2H_2O$. Calculated %: N 2.50.

Dibismuth and Ammonium Salts of Bismutho-dicitric Acid. 330.0 mg of the preceding sample was mixed with 100 ml of water for half an hour. After standing 48 hours, the precipitate was filtered off, washed thoroughly with water and dried at 105°. 59.9% of the dibismuth salt of $2BiCi \cdot BiOOH$ was obtained (instead of the theoretically calculated 61.2%), in the form of a white, microcrystalline sample, insoluble in water and lacking in acid properties. The sample was insoluble in ammonia but soluble in an ammoniacal solution of bismuth citrate.

84.5 mg substance: 57.0 mg Bi_2O_3. 66.2 mg substance: 32.8 mg CO_2; 7.1 mg H_2O. Found %: Bi 60.51; C 13.52; H 1.20. $C_{12}H_{11}O_{16}Bi_3$. Calculated %: Bi 60.39; C 13.88; H 1.07.

The aqueous solution was steamed off on the water bath after filtration of the dibismuth salt and dried at 105° (4 hours).

19.9 mg substance: 0.9 ml 0.1 N HCl. 26.5 mg substance: 9.4 mg Bi_2O_3. Found %: N 6.34; Bi 31.81. $(NH_4)_2Ci \cdot BiCi \cdot H_2O$. Calculated %: N 6.37; Bi 31.70.

Further heating of the sample $3NH_3 \cdot 4BiCi \cdot 2H_2O$ at 130° (22 hours; see Figure 2) leads to the formation of a brown product, containing 1 less mole of ammonia (with an overall loss in weight of 19.45%).

202.0 mg substance: 2.25 ml 0.1 N HCl. Found %: N 1.56.

Upon treatment of the product with water, followed by thorough washing, there was obtained 88.17% of basic bismuth citrate $2BiCi \cdot BiOOH$ in the form of an almost white product.

SUMMARY

1. Changes in the composition of ammonium bismuth citrate upon heating at 50, 80, 105 and 130°, and upon boiling in benzene, were studied.

2. Two basic bismuth citrates ($BiCi \cdot BiOOH$ and $2BiCi \cdot BiOOH$), were obtained, the ammonium salts of two acid bismuth citrates ($BiCi \cdot CiH_3 \cdot H_2O$ and $2BiCi \cdot CiH_3 \cdot 2H_2O$) and ammonium and barium citrobismuthates

$Ba(CiBi \cdot OH)_2$ and $NH_4(CiBi \cdot OH)$, where Ci denotes the citric acid residue.

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ACTIVE CARRIERS DURING HYDROGENATION

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Catalytic hydrogenation requires activation on the surface of the catalyst of both the hydrogen and of the hydrogenated compound. Naturally, the most favorable conditions for activation of the separate components may not coincide and an increase in temperature almost always changes not only the speed of the primary reaction, but also the relative concentrations of the reacting substances on the catalyst surface. As a result, there is observed a negative temperature coefficient above 40° [1] when a majority of organic compounds are hydrogenated in the presence of elementary nickel catalyst. By activating, or inactivating, the catalyst, it is possible to increase or to decrease the activation of one of the reacting components. Thus, for example, when Pt, Pd or Rh is deposited upon nickel catalyst, the hydrogen is almost always principally activated, whereas Os, Ru and Re actually lower the activity of nickel catalyst. At room temperature osmium black displays activity upon hydrogenation of the double bond, the carbonyl group and the nitro group [2], during which time the hydrogenation proceeds stepwise. Under these conditions, acetylenic hydrocarbons do not fully hydrogenate, which is explained by the competition between the hydrogen and the acetylene group on one and the same sections of the catalyst. During hydrogenation on Pt, Pd or Ni, both the adsorbed and the dissolved hydrogen take part in reaction. To a lesser extent the question of activation of the unsaturated component during reaction has been studied. In this case it may be expected that the structural correspondence between catalyst and reacting molecule will be of primary importance. An assumption has been made that superficially completely inactive osmium and ruthenium blacks actually activate the double bond and active hydrogen is lacking only on their surface. Following deposition on their surfaces of palladium or of platinum, which activate hydrogen particularly well, the potential possibilities of such "active carriers" should be manifested and it should be possible to obtain highly active catalysts. This assumption was fully confirmed, using the hydrogenation of dimethylacetylenylcarbinol.

EXPERIMENTAL

(With the assistance of N. Sinaiskaya and M. Zakharova)

The hydrogenation was studied in 96% ethanol solution under conditions described earlier [3]. For catalysts were used: Pt, deposited on $BaSO_4$, or on $BaSO_4$ coated first with Os, and also by Pd on $BaSO_4$ coated with ruthenium. The active carriers were prepared according to the method of N. D. Zelinsky [4], calculated in such amount as to obtain a 20% Os or Ru content on $BaSO_4$. The "active carriers" were dried at room temperature in a dessicator over H_2SO_4. Their characteristic activity was examined by hydrogenation of nitro benzene and was found to be equal to zero. Part of the Os–$BaSO_4$ and Ru–$BaSO_4$ was reduced at 200° for 4 hours and subsequently remained inactive. A weighed portion of "active carrier", equal to 2 g, was transferred to a flask with the aid of 15 ml of alcohol; there was also introduced, by a pipet, a defined volume of chlorplatinate or of palladium chloride solution. The flask was shaken for 30 minutes, for better adsorption of the promoter, and the catalyst was further saturated with hydrogen for 30 minutes at 25°. After saturation, there was placed in the flask a defined weight of dimethylacetylenylcarbinol and 10 ml of alcohol was added. The system was washed rapidly with hydrogen, the motor switched on and readings on absorbed hydrogen started.

Hydrogenation of Dimethylacetylenylcarbinol on Catalysts Pt–$BaSO_4$ and Pd–$BaSO_4$. It was found that the hydrogenation rates of the double and of the triple bond on Pt and Pd deposited on $BaSO_4$ differed. In Fig.1 is represented a series of kinetic curves for the hydrogenation of dimethylacetylenylcarbinol on Pt–$BaSO_4$ catalyst. One peculiarity is characteristic for all curves – the reaction rate remains almost stationary up to the absorption of approximately 70-75% of the calculated volume of hydrogen and then increases sharply.

It may be assumed that on the first horizontal segment, linkage of one hydrogen molecule to the triple bond occurs, and simultaneously partial hydrogenation of the ethylene derivative produced starts. As soon as hydrogenation of the triple bond is terminated, the double bond starts to hydrogenate with much greater speed. To examine this assumption, the experiments were interrupted at the moment when the increase in reaction rate started. The products of incomplete hydrogenation were poured off rapidly from the catalyst and tested for the presence of hydrogen at the triple bond by the use of ammoniacal silver nitrate; in all cases the absence of the acetylenic alcohol was established.

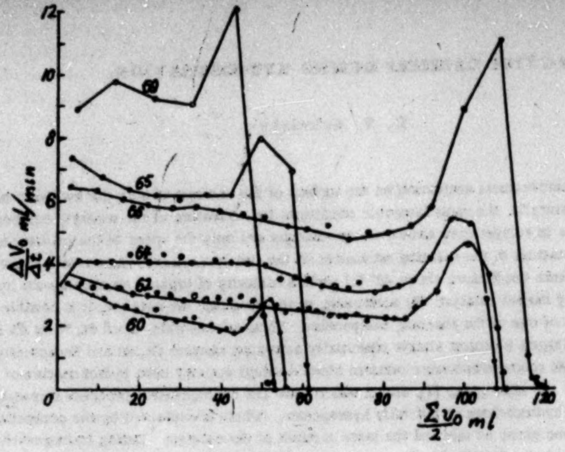

Fig. 1. Hydrogenation of Dimethylacetylenylcarbinol on Pt–$BaSO_4$ Catalyst. ($BaSO_4$ 0.2 g, ethyl alcohol 25 ml).

Expt. No.	Quantity of Pt (g)	Temperature	Quantity of Carbinol (ml)
60	0.00103	25°	0.12
62	0.00103	25	0.24
64	0.00103	40	0.24
65	0.00206	25	0.13
66	0.00206	25	0.26
69	0.00206	40	0.12

It is known that Pt dissolves very little hydrogen and, furthermore, under our conditions, the Pt atoms either form very fine crystals or penetrate into the incomplete lattice work of the carrier: thus adsorbed hydrogen plays the principal role in hydrogenation. Compounds with a triple bond adsorb very well on the surface of the platinum metal group, and, in addition, they are activated on the centers, that are similar to the centers which activate the hydrogen.[1]. As a result of this competition, the speed of hydrogenation of the triple bond on platinum catalysts is usually smaller than the speed of hydrogenation of the double bond. In the absence of compounds with a triple bond, the hydrogen concentration on the surface increases. In complete accordance with this view, as the curves of Fig. 1 indicate, the hydrogenation speed of the triple bond decreases with the dimethylacetylenylcarbinol increase in concentration and the hydrogenation speed of the double bond increases.

For characterization of curves of a similar type, we are introducing the value, a, representing the relation between the maximum speed of hydrogenation to the average speed of hydrogenation of the triple bond (the first segment of the curve). The value, a, as experiments indicate, depends very little upon the activity of the catalyst, upon the quantity of Pt deposited upon $BaSO_4$, or upon the temperature. Thus, in a whole series of experiments with 0.12 ml of dimethylacetylenylcarbinol, upon a change in quantity of Pt from 0.00103 to 0.00412 g, and a temperature from 25 to 40°, the relation of speeds a changed only from 1.1 to 1.3, i.e., within the range of experimental error. Contrariwise, the value a, is very sensitive to concentration change, and under the same conditions, with 0.24 ml of dimethylacetylenylcarbinol, fluctuated from1.7 to 2.2.

It should be noted that with an increase in temperature the hydrogenation speeds of the triple and the double bond increase, but the former rises more rapidly and the relation of the speed a decreases somewhat. This phenomenon is quite understandable if one assumes that, with temperature rise under the conditions involved, the speed of the primary reaction increases and general adsorption decreases.

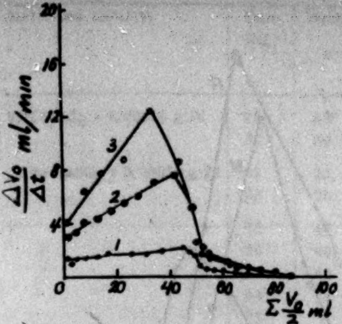

Fig. 2. Hydrogenation of Dimethylacetylenylcarbinol on catalyst Pd–$BaSO_4$. ($BaSO_4$ 0.2 g., Pd 0.00012 g, ethyl alcohol 25 ml).

Expt. No.	Temperature
1	1°
2	25
3	40

TABLE 1

Added Pt (g)	Carbinol taken (ml)	Temperature	a average
0.00051	0.12	25°	4.20
	0.24	25	4.70
	0.12	40	3.85
0.00103	0.12	25	2.63
	0.12	40	2.50
	0.24	40	4.30
0.00206	0.12	25	1.95
	0.24	25	3.00

In Fig.2 is represented a series of curves on another catalyst, Pd–$BaSO_4$. In this case the correlation of speeds is entirely different: the reaction speed in the first half of the process is considerably greater than in the second and consequently the triple bond hydrogenates more rapidly than the double bond. Selectivity of the catalyst in this case is considerably greater and the break in the speed, corresponding to a loss of a triple bond in the compound, is observed after absorption of 55-68% of the calculated quantity of hydrogen (reaction with ammoniacal $AgNO_3$). A similar course of the curves in the presence of Pd, which is similar in lattice structure to that of Pt, can be related only to the participation of dissolved hydrogen in the reaction. It is known that Pd dissolves hydrogen readily and that this hydrogen takes part in the reaction, as we have shown earlier [3]. In this instance the hydrogen and the acetylene derivative activation are basically related to the different surface sections, or more correctly, with the mass of the catalyst. The gradual increase in speed during the first half of the process can be related to the increased role of adsorbed hydrogen by the rate of concentration decrease of the compound with the triple bond. Thus, in the case of palladium catalyst, it is impossible to limit oneself to examination of the role of dissolved hydrogen only. It is necessary to take into account the gradual increase in role of the adsorbed hydrogen. The variable correlation of hydrogenation speeds of the triple and double bonds in the presence of Pt and Pd on $BaSO_4$ made it of particular interest to study the effect of Os and Ru as a coater from the point of view of clarifying this correlation.

As has already been mentioned, Os and Ru on $BaSO_4$ were found to be entirely inactive in the hydrogenation reaction. Both metals have the hexagonal lattice with parameters: Os a 2.7244 A, with 4.3044 A , Ru a 2.695 A, with 4.273 A , and can, from structural considerations, at low temperature, only result in activation of the double bond by a given amount of hydrogen and not the triple bond.

Hydrogenation of Dimethylacetylenylcarbinol on catalyst Pt–[Os–$BaSO_4$]. A series of curves is represented in Fig.3, which were obtained in the presence of Os. The shape of the curve remains the same under all conditions, and is similar to the curves obtained in the absence of Os. However, the hydrogenation speed of the triple bond is almost unchanged and the hydrogenation speed of the double bond increases sharply. As a result, the value, a, increases also. Thus, the presence of Os can be considered to be catalyzing only in relation to the second part of the process, i.e., to the hydrogenation of dimethylvinylcarbinol. Upon increase in concentration of the dimethylacetylenylcarbinol, the hydrogenation speed of the triple bond decreases and the hydrogenation speed of the double bond increases (curves for Experiments 5 and 6, 9 and 10, 30 and 31, 16 and 17).

The deductions made become more graphic when the average values for "a" (Table 1) are calculated.

As can be seen from Fig.3 and from the data of Table 1 during the small steps in the filling of the platinum surface, an acceleration in double bond hydrogenation is noticed.

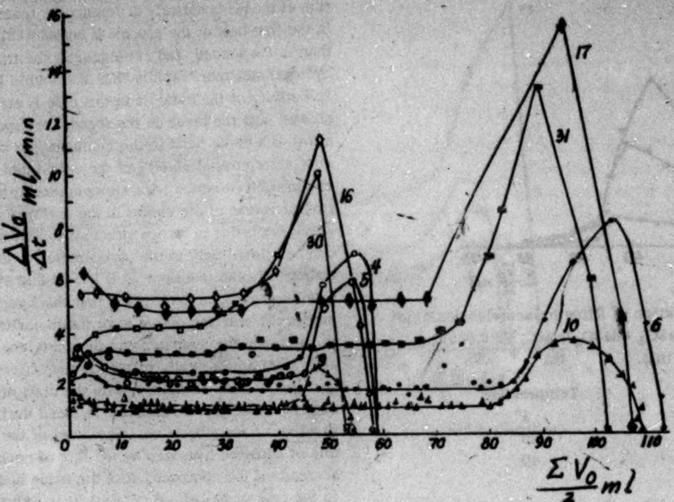

Fig. 3. Hydrogenation of dimethylacetylenylcarbinol on catalyst Pt–[Os–BaSO$_4$]. (Os–BaSO$_4$ 0.2 g, ethyl alcohol 25 ml).

Expt. No.	Pt Quantity (g)	Temperature	Carbinol quantity (ml)
4	0.00103	25°	0.12
5	0.00103	25	0.12
6	0.00103	25	0.24
9	0.00051	25	0.12
10	0.00051	25	0.24
30	0.00103	40	0.12
31	0.00103	40	0.24
16	0.00206	25	0.12
17	0.00206	25	0.24

For a given quantity of Pt during the greatest changes in activity of the catalyst the correlation of the hydrogenation speeds, a, is almost unchanged. The same regularities were found by the author upon subsequent filling up of the Os–BaSO$_4$ surface by platinum, beginning with from 0.00021 to 0.00165 g of Pt for 0.2 g of "active carrier". Pt on Os–BaSO$_4$ was found to be a very stable catalyst and it is possible to conduct more than 10 experiments on the one sample without noticeable lowering of the activity.

Similar series of experiments were carried out with Pt, deposited on Os–BaSO$_4$, previously reduced at 200°. It is necessary to note that the catalyst in this case is even more stable and active. A very interesting phenomenon was observed after prolonged work with one and the same weighed sample of reduced catalyst: the activity of the catalyst decreased from experiment to experiment and the relation of the hydrogenation speeds of the double and the triple bonds, a, increased. This experimental result can be explained by the fact that the Pt atoms are able in time to penetrate deeply into the crystalline lattice of the Os–BaSO$_4$ carrier, as the result of which "a" increases.

Hydrogenation of dimethylacetylenylcarbinol on catalyst Pd–[Ru–BaSO$_4$]. The kinetic hydrogenation curves are represented in Figs.4, 5, 6. The triple bond hydrogenates in this case considerably more rapidly than the double bond. Comparative data on hydrogenation in the presence of, and in the absence of, Ru are given in Table 2 for the two series of experiments.

TABLE 2

Series and catalyst	Expt. No.	Temp.	Carbinol taken (ml)	Maximum speed (ml/min.)	K for hydrogenation of double bond	Duration of hydrogenation (in min.)	
						of the triple bond	of the double bond
VIII $BaSO_4$ + 0.00036 g Pd	29	25°	0.2	26.5	0.87	2	22
	30	40	0.2	38.7	1.60	1	14
IX Ru–$BaSO_4$ + 0.00036 g Pd	32	25	0.2	30.0	2.15	2	7
	33	25	0.2	30.5	1.88	2	7
	35	40	0.2	48.3	3.73	1	6
	36	40	0.4	51.1	4.01	2	7
	37	40	0.6	50.7	4.01	3	10
	34	25	0.2	28.0	–	2	8
	31	1	0.2	10.0	0.44	5	27
	38	25	0.2	25.5	1.88	2	9
	39	25	0.4	26.7	1.80	4	13
After 72 hours of standing for the catalyst	40	1	0.4	7.4	0.28	15	45

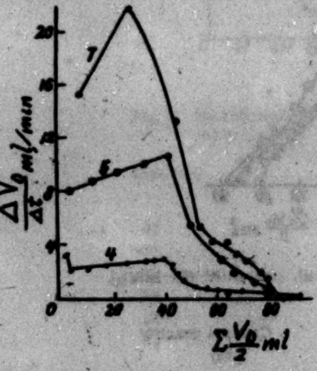

Fig. 4. Hydrogenation of dimethylacetylenylcarbinol on catalyst Pd–[Ru–$BaSO_4$]. (Ru–$BaSO_4$ 0.2 g Pd 0.00012 g, ethyl alcohol 25 ml).

Expt. No.	Temperature
4	1°
5	25
7	40

TABLE 3

Temp. interval	Catalyst			
	Pd–$BaSO_4$		Pd–[Ru–$BaSO_4$]	
	E of triple bond hydrogenation (cal/mol)	E of double bond hydrogenation (cal/mol)	E of triple bond hydrogenation (cal/mol)	E of double bond hydrogenation (cal/mol)
1-25°	8-9000	7-8000	7-8000	8-9000
25-40	4-5000	6-7000	5-6000	6-7000

As can be seen from the data of Table 2 and the curves of the graphs, the average speed of hydrogenation in the presence of Ru at all temperatures is considerably higher. However, the hydrogenation time of the triple bond, in the presence of Ru, is the same as without it, while the hydrogenation time of the double bond in the presence of Ru decreases from 22 to 7 minutes, i.e., more than threefold. The relation of hydrogenation speed $\frac{K(Ru)}{K(\text{without } Ru)}$ constitutes: at 25°, 2.3; at 40°, 2.33; of maximum speed at 25°, 1.18; at 40°, 1.25. In all other series of experiments the hydrogenation speed of the double bond also increases more rapidly than the hydrogenation speed of the triple bond. The presence of Ru starts to become noticeable at elevated temperature (40°), evidently, as the result, the activation of the unsaturated bonds over Ru is hampered by low temperature. As can be seen from the data of Table 1 and of Fig. 6, the maximum hydrogenation speed is almost independent of the concentration of dimethylacetylenylcarbinol in solution. The catalyst Pd–[Ru–$BaSO_4$] is very stable and all experiments of the series were carried out with one catalyst. It should be noted that with an increase in the quantity of palladium at a constant quantity of Ru the effect of the latter begins to weaken and the catalyst approaches that of the catalyst Pd–$BaSO_4$.

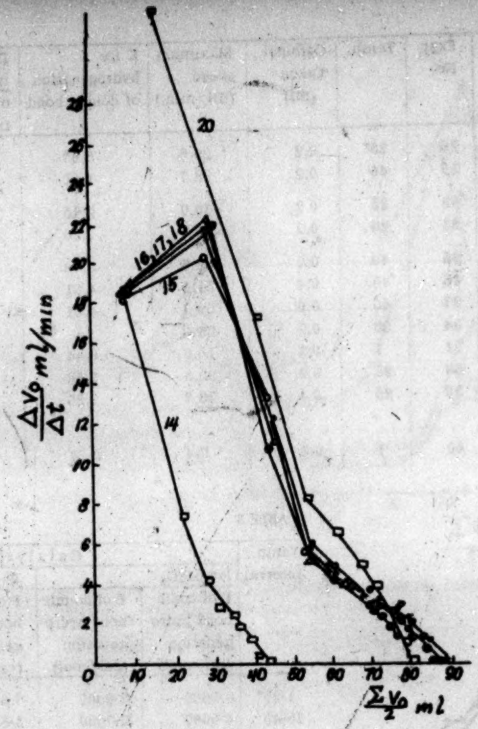

Fig. 5. Hydrogenation of dimethylacetylenylcarbinol with catalyst Pd-[Ru-BaSO$_4$]. (Pd 0.00024 g).

Expt. No.	Temperature	Carbinol quantity (ml)
14	25°	0.1
15,16,17,18	25	0.2
20	40	0.2

Upon deposition of 0.00048 g of Pd, the difference in the properties of the catalysts with Ru becomes evident only at high temperature. The activation energies for the hydrogenation of the triple bond and of the double bond are found on the basis of 13 series of experiments to be variable for catalysts with and without Ru (Table 3).

The activation energy for the triple bond and for the double bond hydrogenation is considerably higher in the temperature interval 1-25° than in the interval 25-40° as can be seen from the data of Table 3.

At the elevated temperatures, the ability of the unsaturated compound to extract dissolved hydrogen from the catalyst increases and along with it the quantity of hydrogen adsorbed on the surface is decreased. The conjugation of the two factors augments the role of dissolved hydrogen, of which diffusion there is naturally a small temperature coefficient. In almost all cases the activation energy for hydrogenation of the triple bond was found to be lower than that for the double bond.

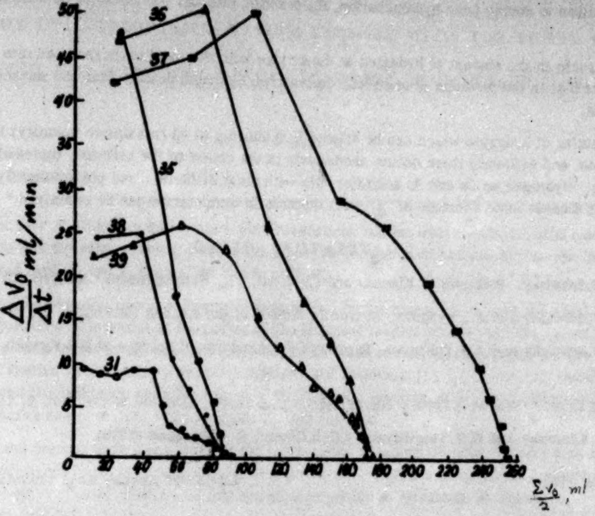

Fig. 6. Hydrogenation of dimethylacetylenylcarbinol with Pd – [Ru – $BaSO_4$]. (Pd 0.00036 g).

Expt. No.	Temperature	Carbinol quantity (ml)
31	1°	0.2
38	25	0.2
39	25	0.4
35	40	0.2
36	40	0.4
37	40	0.6

SUMMARY

The results obtained by the author indicate the necessity for examining separately the effect of carrier upon the behavior of hydrogen and the hydrogenated compound in hydrogenation reactions. In the case of hydrogenation of dimethylacetylenylcarbinol, Os and Ru, on $BaSO_4$, were found to be the carriers which first of all activate the double bond, regardless of the fact that there is an entirely opposite correlation for hydrogenation speeds for the double and the triple bond, which is conditioned by variable percentage participation in reaction of the dissolved and the adsorbed hydrogen upon Pt and Pd. The different effects of substituents on the hydrogenation speed upon Pt and Pd were also demonstrated by B. A. Kazansky and G. T. Tatevosyan [5]. In the case examined, the structural correlation between the molecule and the catalyst enters into the foreground.

The problem of structural correlation acquires now particular actuality in the light of discussion on the "theory of resonance" and it seems somewhat strange that some authors recently have been prepared to reject entirely this principle in organic catalysis. It is inevitable, no doubt, to reject certain complex elements of symmetry, postulated by the multiple theory and hardly realizable from the point of view of no less obligatory energy correlation.

In the case given, the problem of energy correlation is presented only in the sense of a distinction in the role of adsorbed and dissolved hydrogen. Potentiometric measurements demonstrate that the catalyst potential falls rapidly when compounds with a triple bond are hydrogenated on Pt, regardless of how small the speed of reaction is; during the transition to double bond hydrogenation, the reaction rate and the potential both increase sharply at the same time.

The increase in the amount of hydrogen at the surface with the increase in reaction rate can only be connected with the fact that in the presence of acetylene derivatives, hydrogen desorbs from the surface and passes off into the gaseous state.

The quantity of hydrogen which can be diluted in 0.00048 g of Pd (maximum quantity) is quite insufficient for hydrogenation and evidently there occurs incessantly in the course of the reaction, replenishment of the dissolved hydrogen. Hydrogen on Os and Ru activates only with great difficulty and predominantly at increased temperatures. In this manner some decrease of a with increase in temperature can be explained.

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THE INTERACTION OF ISOPROPYLMAGNESIUM BROMIDE WITH THE ETHYL ESTER OF FORMIC ACID AND WITH THE CHLORANHYDRIDE OF ISOVALERIC ACID

E.B.Sokolova

Upon the interaction of secondary and tertiary alkylmagnesium halides with carboxylic acid esters, and also with the chloranhydrides and the salts of acids, there takes place the formation of ketones of the type $RCOR_1$ and RCOR, where R is an acid radical and R_1 is an alkyl halide radical.

The character of the reaction products formed is determined by the properties of both the alkyl halide and of the acid entering into reaction. The effect of the nature of the Grignard reagent radical and the nature of the acid entering into the composition of the ester, or chloranhydride, in the case of syntheses involving the use of tertiary alkyl halides, has been studied in the many works of A.D.Petrov and coworkers [1], I.I.Lapkin [2], and others [3]. These works demonstrated the influence upon the course of the Grignard synthesis of different compound radicals as regards spatial interferences and chemical activity entering into reaction.

The purpose of the present work was a study of the interactions of secondary alkyl halides with ethers and with chloranhydrides under conditions of synthesis according to Grignard with the examples of isopropyl bromide on the one hand and of the ethyl ester of formic acid and the chloranhydride of isovaleric on the other.

The results of the work carried out demonstrated that in the case of interaction of isopropylmagnesium bromide with ethyl formate, reaction occurs only in the normal fashion and results in the formation of the secondary alcohol diisopropylcarbinol, with a yield of about 40%. The interaction of this ester with tertiary-butylmagnesium chloride leads to the formation of tertiary-butylcarbinol (an abnormal reaction product), according to the data of Favorsky and Kolotova [4].

In the case of interaction of isopropylmagnesium bromide with the chloranhydride of isovaleric acid, reaction occurs according to the normal scheme, in contrast to interaction of isovaleric acid derivatives with tertiary-butylmagnesium chloride [5], but is complicated by a side reaction of reducible character. The reaction occurs principally in the direction of the secondary alcohol, isopropylisobutylcarbinol – the reduction product of the ketone, type $RCOR_1$ and the ester – the esterification product of this alcohol with isovaleric acid.

EXPERIMENTAL

1. Reaction of isopropylmagnesium bromide with the ethyl ester of formic acid. For reaction there were taken: 160 g (1.3 mole) of the alkyl halide with b.p. 59-60°, 29 g (1.2 g-atom) of magnesium shavings, and 45 g (0.6 mole) of the ester with a b.p. of 54°. The reaction was carried out in the usual manner, the ester being added to the Grignard reagent. The secondary alcohol – diisopropyl carbinol, to the amount of 28 g, was separated from the reaction products which constituted about 40% of the theoretical yield, on the basis of ester taken for the synthesis. The structure of the derived alcohol was proved by its oxidation to the corresponding ketone, from which was prepared the semicarbazone, with a m.p. of 157°. An attempt to find among the reaction products a combination of the type $RCOR_1$ and its corresponding reduction product (in the case of formic acid and isopropylbromide, the presence of isobutyric acid and isobutyl alcohol) was unsuccessful.

2. Reaction of isopropylmagnesium bromide with the chloranhydride of isovaleric acid. For reaction were taken: 210 g (1.7 mole) of isopropyl bromide, 38.5 g (1.6 g-atom) of magnesium shavings and 97 g (0.8 mole) freshly distilled chloranhydride of isovaleric acid. After removal of ester, the reaction product was distilled off from a Favorsky flask in 5-degree fractions. The maximum yield of product corresponded to a b.p. of 150-155° (12.9 g) and at 155-160° (12.0 g). Anticipating the presence of the secondary alcohol – isopropylisobutylcarbinol – in these fractions formed by reduction of the ketone, $RCOR_1$, the normal reaction product, we conducted the following tests: 1) percent determination of hydroxyl group in the fraction with the b.p. of 155-160° (corresponding to isopropylisobutylcarbinol, boiling in the range of 156-158° according to the literature data) and 2) oxidation of the 155-160° fraction and test on the oxidation product for the ketone group.

Determination of the percent hydroxyl group in the 155-160° b.p. fraction according to the method of Verley, indicated the presence of 9.1% of OH group, which corresponds to an alcohol content in the fraction of about 70% of the composition $C_3H_7CHOHC_4H_9$.

A separate sample of the fraction with b.p. 155-160° was oxidized by chromic acid mixture. Upon treatment of the oxidation products with semicarbazide a copious precipitate of crystalline derivative, with a m.p. of 143°, was obtained. (According to the literature data, the semicarbazone of isopropylisobutylketone melts at 142°).

3.39 mg substance: 0.683 ml N_2 (22°, 746 mm). 3.14 mg substance: 0.629 ml N_2 (22°, 746 mm).
Found %: N 22.88, 22.79. $C_9H_{19}ON_3$. Calculated %: N 22.7.

The fractions with b.p. 140-145° and 145-150° were combined and tested for the presence of ketone of the type $RCOR_1$. As a result of the treatment of the fraction with semicarbazide a semicarbazone precipitated, with a m.p. of 143°. A sample mixed with the semicarbazone of isopropylisobutylketone did not give a depression.

An attempt to obtain the semicarbazone of a ketone of the type RCOR from the fraction with b.p. 160-170° gave negative results.

The fraction with a b.p. of 220-230°, obtained by distilling off the reaction products in significant quantity (7.4 g), was analyzed for ester content. Elementary analysis showed, from the C and H content, that the product examined comes very near to the ester of isovaleric acid and the isopropylisobutylcarbinol of the composition $C_4H_9COOC_8H_{17}$.

5.67 mg substance: 15.14 mg CO_2; 5.84 mg H_2O. 4.70 mg substance: 12.58 mg CO_2; 4.89 mg H_2O.
Found %: C 72.82, 73.00; H 11.52, 11.64. $C_{13}H_{26}O_2$. Calculated %: C 72.9; H 12.1.

A few grams of the fraction with b.p. 220-230° was saponified with 15% alcoholic alkali (KOH) for several hours. The saponification products were examined for the presence of alcohol and acid. The oily layer, which floated up after dilution of the saponification products with water, was separated, washed with water, dried and distilled. The temperature of the product obtained was within the limits 153-163°. Identity of the obtained product with that of the alcohol – isopropylisobutylcarbinol – was proved by its oxidation to the corresponding ketone, from which was obtained the semicarbazone with m.p. 142°. A mixed sample did not show melting point depression.

The water–alcohol layer of the saponification products was acidified with nitric acid after removal of the alcohol and the organic acid was then precipitated in the form of its silver salt.

0.6048 g substance: 0.3148 g Ag. Found %: Ag 52.05. C_4H_9COOAg. Calculated %: Ag 51.67.

SUMMARY

1. It was demonstrated that the secondary alcohol – diisopropylcarbinol – is obtained in 40% yield by interaction of isopropylmagnesium bromide with ethylformate.

2. In the case of interaction between isopropylmagnesium bromide and the chloranhydride of isovaleric acid, the reaction goes in the direction, principally, of the formation of secondary alcohol, isopropylisobutylcarbinol, which is the product from the reduction of the ketone, $RCOR_1$, and of the ester which is the product of esterification of this alcohol with isovaleric acid.

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SELECTIVE MALONIC SYNTHESIS

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The malonic synthesis, involving dihaloid derivatives, has not yet been studied insufficient detail. As is known, the reaction proceeds mainly in three directions upon interaction of sodium malonic ester with dihaloid derivatives and forms the following mixture of products:

$$\text{(I)}\quad X(CH_2)_nX + NaCH(COOC_2H_5)_2 \rightarrow X(CH_2)_nCH(COOC_2H_5)_2.$$

$$\text{(II)}\quad X(CH_2)_nCH(COOC_2H_5)_2 + NaCH(COOC_2H_5)_2 \rightarrow (C_2H_5OCO)_2CH(CH_2)_nCH(COOC_2H_5)_2.$$

$$\text{(III)}\quad X(CH_2)_nCH(COOC_2H_5)_2 \rightarrow \boxed{(CH_2)_nC}(COOC_2H_5)_2.$$

Up to the present time, a reaction of the type given was conducted primarily for the purpose of obtaining the esters of cyclic or of polybasic acids. There are comparatively few known works, the purpose for which was found to be the derivation of intermediately-formed esters of the halogen-substituted alkylmalonic acids; thus the conditions for the formation of these substances, and also their reactions, have received little study.

The following haloidsubstituted monoalkylmalonic esters are described in the literature: 1) β-chlorethylmalonic ester, obtained by N.Ya.Demyanov and V.V.Feofilaktov [1] through the addition of HCl to cyclopropane-1,1-cyanocarboxylic ester in the presence of alcohol; 2) β-Bromethylmalonic ester [2], obtained by addition of HBr to cyclopropane-1,1-dicarboxylic ester; 3) γ-chlorpropylmalonic ester [3]; 4) γ-brompropylmalonic ester [4]; 5) γ-iodopropylmalonic ester [5], resulting from interaction of sodium malonic ester with 3-chlor-1-brompropane, 1,3-dibrompropane and 3-chlor-1-iodopropane; 6) γ-chlorisobutylmalonic ester, obtained by B.A.Kazansky and M. Yu.Lukina [6] from sodium malonic ester and 3-chlor-1-brom-2-methylpropane; 7) δ-chlorbutylmalonic ester [26], resulting from sodium malonic ester and 4-chlor-1-brombutane; 8) ζ-iodhexylmalonic ester, obtained by V.P.Golmov [7] from sodium malonic ester and hexamethylene iodide; 9) β-bromoctylmalonic ester [27], resulting from addition of brommalonic ester to octene-1, and, finally, 10) κ-bromdecylmalonic ester [8], derived from sodium malonic ester and decamethylene bromide. Upon the interaction of equimolecular quantities of sodium malonic ester and a dihaloid derivative containing two atoms of one and the same halogen, the corresponding haloid-substituted alkylmalonic ester results in negligible yield.

The author of the present article has demonstrated [9] that γ-brompropylmalonic ester can be obtained with a yield 70% of theory if there can be removed at the same time the side reactions of formation of the ester of cyclobutane-1,1-dicarboxylic acid and also the ester of pentane-1,1,5,5-tetracarboxylic acid (reactions II and III). Reaction (III) can be retarded by using a large excess of malonic ester, whose presence in the reaction mixture shifts reversible reaction (IV) to the left:

$$\text{IV.}\quad BrCH_2CH_2CH_2CH(COOC_2H_5)_2 + NaCH(COOC_2H_5)_2 \rightleftarrows BrCH_2CH_2CH_2CNa(COOC_2H_5)_2 + CH_2(COOC_2H_5)_2.$$

and decreases the concentration of sodium-γ-brompropylmalonic ester, and consequently the cyclization speed of the latter.

Reaction (II) can also be suppressed to a considerable degree if a large excess of trimethylene bromide is used, together with the excess of malonic ester, in accordance with the law of mass action. Similar results were obtained by the author [7] upon reaction of hexamethylene iodide with sodium malonic ester, and by Ziegler [8] upon reaction of decamethylene bromide with the latter.

In the present work we have tried first of all to explain to what extent the given procedure is applicable for obtaining haloidsubstituted alkylmalonic esters with other alkyl radicals. For this purpose, we have reacted sodium malonic ester with a series of dihaloid derivatives, the atoms of which halogen are located in positions 1,2; 1.3; 1.4 and 1.5 to each other.

The results of these, and also of earlier described experiments [7,8,9], led to the following conclusions. Upon reacting sodium malonic ester with 1,3; 1,5 and 1,6 dihaloid derivatives with unbranched chain, the corresponding haloid-substituted alkylmalonic esters are formed in good yields, the amount of which is determined by the excess of dihaloid derivative. It can be calculated, beforehand, what yield of haloid-substituted alkylmalonic ester will be obtained in each individual case, upon applying a given excess of dihaloid derivative.

This calculation is based upon the following theoretical considerations. The speeds of reactions (I) and (II) are expressed by the following equations:

$$\frac{dx}{dt} = k_1(a-x)(b-x-y), \tag{I}$$

$$\frac{dy}{dt} = k_2(x-y)(b-x-y), \tag{II}$$

where: $\underline{a}$ and $\underline{b}$ = initial concentrations of the dihaloid derivative and the sodium malonic ester, and $\underline{x}$ and $\underline{y}$ = the concentrations of the products of reactions (I) and (II) formed in time $\underline{t}$ If k_1 is taken to be equal to k_2, which is quite justifiable experimentally, as can be seen from the data of table 1, then from the equations for the reaction rates is obtained:

$$\frac{dy}{dx} = \frac{x-y}{a-x} \tag{III}$$

Integrating equation (III), there is found:

$$x-y = 2.3(a-x)\log\frac{a}{a-x} \tag{IV}$$

Taking $x + y$ as 100%, the yield of haloidsubstituted alkylmalonic ester $(\underline{x-y})$ can be calculated. In Table 1 the calculated results are compared with the yields, obtained experimentally at various values for $\underline{a}$.

Upon reaction of sodium malonic ester with 1,4-dibromoderivatives, by the application of as much as 4 times the quantity of malonic ester as against theory it is still not possible to decrease to any considerable degree the cyclization of δ-bromalkylmalonic ester and thus the principal reaction product is found to be in this case the compound with a five-membered ring for the molecule and the δ-bromalkylmalonic ester is formed in yield only 3-5% of the theoretical. The reason for such poor yield is apparently the large constant for rate of formation of the five-membered ring; thus, even with a negligible concentration of the sodium derivative of δ-bromalkylmalonic ester in the reaction mixture, the reaction is directed principally in the direction of formation of the compound with a five membered ring, which results in a yield about 75% of the theoretical. This assumption is in agreement with the data in Table 3 of the present work and also with the experiments of Freundlich and Solomon [24] which had to do with measuring the rate constant for the formation of various cyclic imines. The results of their measurements demonstrate that the rate constant for the formation of the five-membered ring is approximately 800 times greater than that of three-membered and 70 times larger than of the six-membered ring. Bennett and co-workers [25], examining the relative ease of cyclization of β- and δε-chlorsulfites, have also found that the rate constant for the formation of the five-membered ring is 76 times greater than that of the six-membered.

TABLE 1

Substance	haloidalkylmalonic ester yield (in %)		
	a = 100%	a = 200%	a = 400%
$BrCH_2CH_2CH_2CH(COOC_2H_5)_2$	36.0	–	70.3
$ICH_2CH_2CH_2CH(COOC_2H_5)_2$	41.4	58.0	–
$BrCH_2(CH_2)_3CH_2CH(COOC_2H_5)_2$	40.9	60.4	–
$ICH_2(CH_2)_4CH_2CH(COOC_2H_5)_2$	33.8	51.9	–
$BrCH_2(CH_2)_5CH_2CH(COOC_2H_5)_2$	–	64.4	–
Average	38.0	58.7	70.3
Calculated by formula (IV)	36.6	60.6	78.4

The same low yields of intermediate products are obtained upon interaction of sodium malonic ester with 1,2-dihaloid derivatives. The authors were not able to obtain the β-bromethylmalonic ester by reacting sodium malonic ester with ethylene bromide- when ethylene chloride was used, the resulting β-chlorethylmalonic ester resulted in yield of only 8% of theory. The principal reaction product in both cases is cyclopropane-1,1-dicarboxylic ester. The reason for such a peculiar course of action is not clear. It is apparently not possible to assume that the results obtained are conditioned by the large rate constant for formation of the three-membered ring, because cyclopropane-1,1-dicarboxylic ester results from β-bromethyl malonic ester, according to the data of Kuster and Grassner [2] with a poorer yield than, for example, cyclobutane-1,1-dicarboxylic ester from γ-brompropylmalonic ester [10] (Table 3); however, under the same conditions, the latter results in a yield of 70% of theory [9].

Thus, the results of our experiments demonstrate that to obtain β- or δ-haloidalkylmalonic esters by the use of malonic ester, it is disadvantageous to proceed from the symmetrical dihaloid derivatives. For derivation of δ-bromalkyl malonic esters, a second method described below can be employed, namely the addition of hydrogen bromide to the alkenylmalonic esters. As is known, the γ-brompropylmalonic ester was obtained by this procedure from allylmalonic ester [10], and also α-bromdihydrocinnamylidenemalonic ester from cinnamylidene ester [11]. In the present work we have synthesized a new alkenylmalonic ester by reacting sodium malonic ester with 5-bromhexene-1, namely α-methyl-δ-pentenylmalonic ester $CH_2{=}CHCH_2CH_2CH(CH_3)CH(COOC_2H_5)_2$. Upon addition of HBr to it in ether solution, α-brom-δ-methylamylmalonic ester results in the form of a stereoisomeric mixture, the structure of which was proven by its method of cyclization, at which time there resulted a mixture of stereoisomeric 2,5-dimethylcyclopentane-1,1-dicarboxylic esters, described earlier by Wislicenous [12] and also by Jacobs and Florsheim [13].

ε-iodamylmalonic ester was also obtained by reacting sodium iodide with ε-bromamylmalonic ester.

In Table 2 the physical properties of the haloidsubstituted alkylmalonic esters obtained by us are compiled.

TABLE 2

Substance	Boiling point	d_4^{20}	n_D^{20}
$ClCH_2CH_2CH(COOC_2H_5)_2$	122-123° (3 mm)	1.1300/17°	1.4425/17°
$ClCH_2CH_2CH_2CH(COOC_2H_5)_2$ [3]	136° (5mm)	1.1010/21°	1.4434/21°
$BrCH_2CH_2CH_2CH(COOC_2H_5)_2$	132-134° (4 mm)	1.2834	1.4590
$BrCH_2(CH_2)_2CH_2CH(COOC_2H_5)_2$	133-136° (2 mm)	1.2567	1.4594
$BrCH_2(CH_2)_3CH_2CH(COOC_2H_5)_2$	143-144° (1.5mm)	1.2310	1.4609
$CH_3CHBrCH_2CH_2\underset{\substack{\vert\\CH_3}}{C}HCH(COOC_2H_5)_2$ *	145-147° (2 mm)	1.2054	1.4605
$CH_3CHBrCH_2CH_2\underset{\substack{\vert\\CH_3}}{C}HCH(COOC_2H_5)_2$ **	143-144° (2 mm)	1.2075	1.4616
$ICH_2CH_2CH_2CH(COOC_2H_5)_2$	138° (1.5 mm)	1.4601	1.4869
$ICH_2(CH_2)_3CH_2CH(COOC_2H_5)_2$	162° (3 mm)	1.3808	1.4844
$ICH_2(CH_2)_4CH_2CH(COOC_2H_5)_2$ [7]	168° (2 mm)	1.3433	1.4839

Having obtained the above-described haloid-substituted alkylmalonic esters, we have utilized them to solve the question of the relative ease of formation of the smaller polymethylene rings under the conditions of malonic synthesis. This question cannot be regarded as fully clarified up to the present, because in the preceding works based upon a given course, wherein derivation of cyclic esters was conducted without isolation of the intermediate products [14, 15, 16] it is impossible to make proper deductions, because of the side reactions which distort the true picture of cyclization.

Certain polymethylene-1,1-dicarboxylic esters have already been earlier derived from haloidsubstituted alkylmalonic esters. Thus, V. P. Golmov and B. A. Kazansky [3] obtained cyclobutane-1,1-dicarboxylic ester from γ-chlorpropylmalonic ester by reaction of the latter with sodium alcoholate. Wibaut and coworkers [17] have obtained the same ester by reacting solid caustic potash with γ-brompropylmalonic ester. The cyclization of γ-chlorisobutylmalonic ester was also accomplished, with the aid of sodium alcoholate, by B. A. Kazansky and M. Yu. Lukina [6], of γ-brompropylmalonic ester by Walborsky [10], of β-bromethylmalonic ester by Kuster and Grassner [2], and of ζ-iodhexylmalonic ester by V.P. Galmov [7]. The results of these works demonstrate that three- and four-membered rings are formed with ease and in good yields, with the help of the method given. On the other hand, it was found that seven-membered rings are formed with more difficulty under these conditions than the others.

In the present work, the above-mentioned data are supplemented by information on the relative ease of formation of compounds with five- and six-membered rings from δ- and ε-haloidalkylmalonic esters. In view of the fact that δ-brombutylmalonic ester was not obtained in quantity sufficient for the purpose of experimentation with five-membered rings, it was necessary that we limit ourselves to the cyclization of only δ-brom-α-methylamylmalonic ester.

For comparison, γ-iodpropyl- and ε-iodamylmalonic ester were also subjected to cyclization, at which time it was found that the nature of the halogen has little effect upon the yield of cyclic product. Finally, in view of the fact that concentration of γ-brompropylmalonic ester, described earlier [10], was carried out in considerably diluted solution, we have repeated these experiments in solution of high concentration. The data obtained, which characterize the relative ease with which different rings are formed, by the malonic synthesis, are compiled in Table 3.

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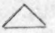
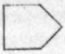
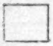
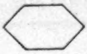
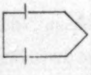
* From meso-2,5-dibromhexane and sodium malonic ester

** From α-methyl-δ-pentenylmalonic ester

TABLE 3

Ring	Yield of cyclic esters (in%)		Ring	Yields of cyclic esters (in%)	
	From bromester	From iodester		From bromester	From iodester
	64.5	–		87.2	–
	71.7	70.0		60.1	61.6
				–	3.0

EXPERIMENTAL

Malonic ester, having a b.p. of 195° (704 mm), d_4^{20} 1.0537; n_D^{20} 1.4140, served as the initial starting material.

δ-Brombutylmalonic Ester

The tetramethylene bromide required for the experiment given was obtained by the method of Marvel and Tannenbaum [18]. Modifications consisted, first of all, in obtaining the ester of γ-phenoxybutyric acid which is sensitive to reduction, not from the nitrile of γ-phenoxybutyric acid, as did the above-cited authors, but rather by the esterification of γ-phenoxybutyric acid, which was prepared from sodium malonic ester and β-bromphenetole [19,20]; secondly, for the reduction of the ester of γ-phenoxybutyric acid, the author applied the method of Prins [21], through which the δ-phenoxybutyl alcohol is obtained more conveniently than in absolute alcohol medium.

Reduction of γ-Phenoxybutyric Acid Ester. 35 g of γ-phenoxybutyric acid ester, dissolved in 100 ml of sulfuric ether, was placed in a flask equipped with mechanical stirrer and dropping funnel, and containing 50 ml of a saturated solution of sodium acetate. 22 g of metallic sodium was gradually added at a temperature of from -5° to -2°, with slow mixing, and simultaneously, 30% acetic acid dropwise. After completion of reaction, water was added until the precipitated salt dissolved, the upper layer was separated, and the lower was extracted once with ether. The ether solution was dried with anhydrous potash, the ether distilled off, and the residue distilled in vacuo, upon which the δ-phenoxybutyl alcohol boiled in the range 145-150° at 10-12 mm. It was in the form of a colorless, oily liquid, which solidified into a crystalline mass upon standing. Yield on the average was 17 g or 60% of theoretical.

The tetramethylene bromide derived from the δ-phenoxybutyl alcohol upon reaction of the latter with hydrogen bromide and sulfuric acid mixture [18], boiled at 69° (7 mm); d_4^{17} 1.8131; n_D^{17} 1.5203.

Reaction of Sodium Malonic Ester with Tetramethylene Bromide. 5.75 g (0.25 g-atom) of metallic sodium was dissolved in 75 ml of absolute alcohol, and 160 g (1 mole) of malonic ester then added, followed by 54 g (0.25 mole) of tetramethylene bromide. The mixture was heated to boiling on a bath for 2 hours, and the reaction then became neutral. After cooling, water was then added, the reaction products were extracted with ether, the ether extraction washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue fractionated in vacuo, during which time three fractions resulted: 1) b.p. up to 84° (mainly 69-74°) at 4 mm - 165 g; 2) b.p. 84-92° at 3 mm - 23 g; 3) b.p. 135-138° at 3 mm - 2.7 g. Negligible residue remained in the flask after boiling as above.

The 84-92° fraction, upon repeated distillation, boiled mostly at 83° (3 mm) and represented cyclopentane-1,1-dicarboxylic ester (yield 86%); d_4^{20} 1.0490; n_D^{20} 1.4435; MR_D 54.02; calculated 54.11.

The 135-138° fractions, combined from the experiments, after repeated distillation in vacuo boiled at 133-136° at 2 mm, and judging from the constants and the analysis results, represented impure δ-brombutylmalonic ester (yield 3.6% of theoretical); d_4^{20} 1.2567; n_D^{20} 1.4594; MR_D 64.22; calculated 64.07.

0.2243 g substance; 0.3705 g CO_2; 0.1347 g H_2O; 0.4337 g substance: 0.2670 g AgBr. Found %: C 45.06. H 6.67; Br 26.22. $C_{11}H_{19}O_4Br$ Calculated %: C 44.75; H 6.44; Br 27.12.

δ-Brom-α-methylmalonic Ester

6.9 g (0.3 g-atom) of metallic sodium was dissolved in 75 ml of absolute alcohol. 192 g (1.2 mole) of malonic ester was added to the alcoholate solution, and then 73.2 g (0.3 mole) of meso-2,5-dibromhexane, m.p. 38-39°, obtained by addition of hydrogen bromide to 5-bromhexene-1. The mixture was heated on a bath to boiling for 6 hours, and then, after cooling, was diluted with water, acidified with sulfuric acid, the reaction products extracted with ether, the ether extract washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue fractionated in vacuo. During this time the following fractions resulted: 1) b.p. up to 78° at 2 mm (mixture of malonic ester with 2,5-dibromhexane) - 205g; 2) b.p. 100-108° at 4 mm - 18.3 g; 3) b.p. 145-147° at 2 mm - 5.4 g. A negligible residue remained in the flask.

The 100-108° fraction, upon repeated distillation in vacuo, boiled mainly at 90-91° (1.5 mm) and was found to be the ester of cis-2,5-dimethylcyclopentane-1,1-dicarboxylic acid. 9.7 g of the latter acid was saponified by alcholic KOH, the alcohol distilled off, the residue diluted with water and acidified with sulfuric acid. During this time there was precipitated 7.7 g (90% of theory) of crystalline substance, which boiled at 81° after recrystallization from aqueous formic acid [13], and represented the acid ester of cis-2,5-dimethylcyclopentane-1,1-dicarboxylic acid.

The 145-147° fraction was found to be impure ester of δ-brom-α-methylamylmalonic acid (yield 5.6 % of theoretical); d_4^{20} 1.2054; n_D^{20} 1.4605; MR_D 73.39; calculated 73.31.

0.1834 g substance; 0.3273 g CO_2; 0.1205 g H_2O. 0.3827 g substance: 0.2142g AgBr. Found %: C 48.66; H 7.31; Br 23.93; $C_{13}H_{23}O_4Br$. Calculated %: C 48.30; H 7.12; Br 24.73.

α-Methyl-δ-pentenylmalonic ester

To a solution of alcoholate, obtained from 11.5 g (0.5 g-atom) of metallic sodium and 130 ml of absolute alcohol, 160 g(1 mole) of malonic ester was added [20], followed by 82 g (0.5 mole) of 5-bromhexene-1. The mixture was heated on a bath to boiling for 12 hours, then, after cooling, was diluted with water, acidified with sulfuric acid, the reaction products extracted with ether, the ether extracts washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue fractionated in vacuo. At first a few grams of the initial bromide (up to 70° at 4 mm) came over, then 71 g of malonic ester (71-73° at 4 mm) and finally 91 g of α-methyl-δ-pentenylmalonic ester of b.p. 110-111° at 2 mm. The resulting ester was in the form of a colorless oily liquid, almost odorless (yield 75.2% of theoretical):

d_4^{20} 0.9809; n_D^{20} 1.4397; MR_D 64.96; calculated 65.08.
0.1112 g substance; 0.2630 g CO_2; 0.0910 g H_2O. Found %: C 64.50; H 9.09. $C_{13}H_{22}O_4$.
Calculated %: C 64.46; H 9.09.

12 g of the substance was saponified while heating by a solution of 10 g KOH in 50 ml of 95% alcohol for 1.5 hours, the liquid diluted further with water, and the alcohol distilled off, the residue acidified by sulfuric acid and extracted 5 times with ether. The ether extraction was dried with anhydrous calcium chloride, and after vaporization of the ether, 8.8 g (95.6% of theory) of the dicarboxylic acid was deposited, which, after two recrystallizations from benzene, had a stable melting point of 106-107°.

0.2134 g substance: 0.4538 g CO_2; 0.1440 g H_2O. Found %: C 58.04; H 7.45. $C_9H_{14}O_4$.
Calculated %: C 58.06; H 7.53.

7.8 g of α-methyl-δ-pentenylmalonic acid was heated for 2 hours in a small flask with a reflux condenser, in a bath of Wood's metal to 180-200°. The liquid, 5-methylheptene-1-ic acid-6, remaining in the flask, boiled at 229-231° (709 mm) upon distilling from a Wurtz flask. The yield was 4.8 g, or 81.3% of theoretical; d_4^{20} 0.9358; n_D^{20} 1.4420; MR_D 40.14; calculated 40.21.

0.2572 g substance: 0.6354 g CO_2; 0.2296 g H_2O. Found %: C 67.38; H 9.92. $C_8H_{14}O_2$.
Calculated %: C 67.60; H 9.86.

Addition of HBr to α-methyl-δ-pentenylmalonic Ester. 30 g of α-methyl-δ-pentenylmalonic ester was dissolved in 50 ml of ether and gaseous hydrogen bromide was passed through the solution cooled in a mixture of snow and salt, to an increase in weight of 23 g. After standing overnight at room temperature, the liquid was poured into water, the reaction product separated, washed with dilute soda solution, then with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue distilled in vacuo. At the same time, about 10 g of initial unsaturated ester was recovered (b.p. 112-113° at 2.5 mm) and 20.8 g of fraction distilling at 143-144° (2.5 mm) and representing δ-brom-α-methylamylmalonic ester (a mixture of stereoisomers); d_4^{20} 1.2075; n_D^{20} 1.4616; MR_D 73.49; calculated 73.31.

0.2429 g substance; 0.4298 g CO_2; 0.1557 g H_2O. 0.2903 g substance; 0.1682 g AgBr. Found %: C 48.21; H 7.12; Br 24.67; $C_{13}H_{23}O_4Br$. Calculated %: C 48.30; H 7.12; Br 24.73.

The substance was in the form of a colorless, oily liquid with the odor of haloidalkylmalonic ester.

The yield (taking into account the initial substance recovered) was 78.1% of theory.

Cyclization of δ-brom-α-methylmalonic ester. 36 g (0.11 mole) of δ-brom-α-methylamylmalonic ester was added to an alcoholate solution prepared from 2.6 g (0.11 g-atom) of metallic sodium and 60 ml of absolute alcohol. Vigorous reaction took place, with strong evolution of heat from the mixture, and precipitation of sodium bromide. The mixture was further heated to boiling on a bath for 2 hours, and upon cooling was poured into acidified water, the reaction products extracted with ether, the ether extract washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue distilled in vacuo, which resulted in 23.4 g (87.2% of theory) of substance, boiling at 105-106° (4 mm) d_4^{20} 1.0159; n_D^{20} 1.4448; MR_D 63.35; calculated: 63.34.

0.2502 g substance: 0.5916 g CO_2; 0.2055 g H_2O. Found %: C 64.46; H 9.12. $C_{13}H_{22}O_4$. Calculated %: C 64.49; H 9.12.

10.2 g of the resulting ester was saponified with a solution of 10 g KOH in 35 ml of 60% alcohol for 1 hour. After dilution with water, removal of the alcohol by distillation, and acidification of the solution with dilute acid, the saponification product separated in the form of a thick, viscous oil, partially crystallizable upon standing. The crystals were filtered with suction and after recrystallization from aqueous formic acid, melted at 81°, thus representing the same acid ester of cis-2,5-dimethylcyclopentane-1,1-dicarboxylic acid as was obtained in the experiment with 2,5-dibromhexane. A mixture of the substances also melted at 81°, by which was finally proven their identity.

The part of the saponification products which remained liquid was not examined further because of its small volume.

ε-Bromamylmalonic Ester

The pentamethylenebromide required for the given experiment was prepared according to the method of Braun [22] and possessed the following characteristics: b.p. 75-77° at 3 mm; d_4^{20} 1.6966; n_D^{20} 1.5140.

6.9 g (0.3 g atom) of metallic sodium was dissolved in 100 ml of absolute alcohol, and 192 g (1.2 mole) of malonic ester was then added, followed by 138 g (0.6 mole) of pentamethylene bromide. The mixture was heated on a bath with reflux condenser for four hours, and then was poured into water, the reaction products extracted with ether, the ether extract washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue fractionated in vacuo. Upon distillation there was obtained: 1) a mixture of malonic ester with pentamethylene bromide, b.p. up to 80° at 3 mm - 234 g; 2) a fraction with b.p. 151-154° at 3 mm - 56 g, and 3) the distillation residue weighing 17 g. The yield of 151-154° fraction was equal to 60.4% of theory.

In the second experiment an excess of pentamethylene bromide was not used. From 6.9 g of sodium, 192 g of malonic ester and 69 g of pentamethylene bromide, there was obtained, by the preceding method, 38 g of ε-bromamylmalonic ester (40.9% of theory).

Upon repeated distillation in vacuo, ε-bromamylmalonic ester boiled at 144-145° (1.5 mm) and was in the form of a colorless, viscous liquid with the characteristic odorof bromalkylmalonic ester; d_4^{20} 1.2310; n_D^{20} 1.4603; MR_D 68.86; calculated 68.69.

0.2144 g substance; 0.3657 g CO_2; 0.1316 g H_2O. 0.2583 g substance: 0.1576 g AgBr. Found %: C46.52; H 6.82; Br 26.03. $C_{12}H_{21}O_4Br$. Calculated %: C 46.60; H 6.80; Br 25.88.

From the residues combined from the first distillations, there was obtained when they were distilled in vacuo, a fraction with b.p. 190° at 1 mm, which represents the ester of heptane-1,1,7,7-tetracarboxylic acid; d_4^{20} 1.0710; n_D^{20} 1.4460; MR_D 96.60; calculated 96.46.

0.1836 g substance: 0.3950 g CO_2; 0.1372 g H_2O. Found %: C 58.67; H 8.30. $C_{19}H_{32}O_8$. Calculated %: C 58.76; H 8.25.

The substance was saponified with an alcoholic solution of caustic alkali; the heptane-1,1,7,7-tetracarboxylic acid formed at the same time was heated in Wood's metal to 200°. The resulting azeloic acid melted at 106-107° after recrystallization from benzene [23].

Cyclization of ε-Bromamylmalonic Ester. To a solution of 3 g (1.13 g-atom) of sodium in 70 ml of absolute alcohol, 40 g (0.13 mole) of ε-bromamylmalonic ester was added. At that time strong heat evolution resulted, and the liquid started to boil. The mixture was further heated on a bath for 2 hours, and after cooling, water was added, the separated oil extracted with ether, the ether extract washed with water, dried with anhydrous calcium chloride, ether distilled off, and the residue distilled in vacuo, from which there resulted a fraction with b.p. 100-103° at 2 mm in the amount of 17.8 g (60.1%). The residue from distillation weighed 8.5 g.

The 100-103° fraction, upon repeated distillation, boiled at 100° (2 mm) and represented the ester of cyclohexane-1,1-dicarboxylic acid; d_4^{20} 1.0405; n_D^{20} 1.4482; MR_D 58.68; calculated 58.72.

ε-Iodamylmalonic Ester

To a solution of 45 g sodium iodide in 120 ml of acetone, 40.2 g of ε-bromamylmalonic ester was added. The solution was heated to boiling on a bath for 2 hours, during which a greater part of the acetone boiled off, water was added to the residue to dissolve the sodium bromide which had precipitated during the reaction, the reaction product was extracted with ether, the ether extract; washed with a weak solution of hyposulfite, then with water, was then dried with anhydrous calcium chloride, the ether distilled off, and the residue distilled in vacuo. 41.2 g of liquid of light yellow color, with b.p. 162° at 3 mm, was obtained upon distillation. The yield was 89.5% of theoretical; d_4^{20} 1.3808; n_D^{20} 1.4844; MR_D 73.81; calculated 73.72.

0.1686 g substance; 0.2490 g CO_2; 0.0912 g H_2O. 0.2178 g substance: 0.1427 g AgI. Found %: C 40.27; H 6.01; I 35.41. $C_{12}H_{21}O_4I$. Calculated %: C 40.45; H 5.90; I 35.67.

Cyclization of ε-iodamylmalonic ester. 40 g (0.11 mole) of ε-iodamyl malonic ester was added to the alcoholate solution from 2.7 g (0.11 g-atom) of metallic sodium and 50 ml of absolute alcohol. After completion of quite a vigorous reaction, accompanied by strong heat evolution and separation of sodium iodide, the mixture was heated on a bath to boiling for 2 hours. After cooling, water was then added, the separated oil extracted with ether, the ether extract washed with weak hyposulfite solution, then with water, dried with anhydrous calcium chloride, the ether distilled off, the ether residue distilled in vacuo, at which time 15.7 g of cyclohexane-1,1-dicarboxylic ester, with b.p. 110° at 4 mm, passed over into the receiver. There remained in the flask 7 g of viscous, non-distillable oil. The yield was equal to 61.6% of theoretical.

γ-Iodpropylmalonic Ester

160 g (1 mole) of malonic ester was added to an alcoholate solution prepared from 5.75 g (0.25 g-atom) of metallic sodium and 75 ml of absolute alcohol, and then 148 g (0.5 mole) of trimethylene iodide, obtained by reaction of sodium iodide in acetone solution with trimethylene bromide, and having a b.p. of 83-85° at 1.5 mm. The reaction mixture was heated on a bath to boiling for 4 hours, was then cooled, poured into water, the separated oil isolated, the water layer extracted with ether, the ether extract combined with the main bulk of reaction product, washed with a weak solution of hyposulfite, then with water, dried with anhydrous calcium chloride, and after removal of the ether by distillation, fractionated in vacuo.

At first the mixture of malonic ester with trimethylene iodide (the fraction with b.p. up to 135° at 2 mm), was distilled, at which there passed over γ-iodpropylmalonic ester with b.p. 135-146° at 2 mm in the amount of 47.6 g (58%). Upon repeated distillation, the product boiled chiefly at 138° (1.5 mm); d_4^{20} 1.4601; n_D^{20} 1.4869; MR_D 64.60; calculated 64.49.

In the second experiment, without the use of trimethylene iodide excess, 34 g (41.4%) of γ-iodpropylmalonic ester was obtained from 5.75 g (0.25 g-atom) of sodium, 160 g (1 mole) of malonic ester and 74 g (0.25 mole) of trimethylene iodide.

Cyclization of γ-iodpropyl ester. 49.2 g (0.15 g-atom) of γ-iodpropylmalonic ester was added to a solution of 3.5 g (0.15 g-atom) of metallic sodium in 80 ml of absolute alcohol. After completion of the spontaneous heat evolution, the mixture was heated on a bath to boiling for 2 hours. The flask contents were then poured into water acidified with sulfuric acid, the reaction product extracted with ether, the ether extract washed with a weak solution of hyposulfite, then with water, dried with anhydrous calcium chloride, and the ether distilled off. The residue, upon distillation in vacuo, boiled at 91° (5 mm). The yield was 21 g of cyclobutane-1,1-dicarboxylic ester, which comprised 70% of theory; d_4^{20} 1.0475; n_D^{20} 1.4360; MR_D 49.92; calculated 49.95.

Cyclization of γ-brompropylmalonic ester. To the alcoholate solution obtained from 6.9 g (0.3 g-atom) of metallic sodium and 160 ml of absolute alcohol, 85 g (0.3 mole) of γ-brompropylmalonic ester [9] was added. The mixture was heated on a bath to boiling for 4 hours, after which it was cooled and poured into water acidified with sulfuric acid. The separated oil was extracted with ether, the ether extraction washed with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue distilled in vacuo. There was obtained 43 g (71.7 %) of cyclobutane-1,1-dicarboxylic ester, boiling at 103° (10 mm); d_4^{20} 1.0472; n_D^{20} 1.4363; MR_D 49.97; calculated 49.95.

β-Chlorethylmalonic Ester

160 g (1 mole) of malonic ester was first added to an alcoholate solution from 5.75 g (0.25 g-atom) of metallic sodium and 75 ml of absolute alcohol, followed by 99 g (1 mole) of ethylene chloride. The mixture was heated on a water bath to boiling for 4 hours, subsequently cooled, poured into water, the lower layer separated, and the upper layer extracted twice with ethylene chloride. The solutions were combined, washed with water, dried with anhydrous calcium chloride, and the ethylene chloride then distilled off at ordinary pressure with a fractionating column. The residue was redistilled in vacuo, and 147 g of a mixture of malonic ester and cyclopropane-1,1-dicarboxylic ester (the fraction with b.p. 80° at 3 mm) and 4.5 g of substance boiling at 121-124° (3 mm) were obtained. The yield constituted 8% of the oretical, on the basis of β-chlorethylmalonic ester.

Fractions combined from the two experiments, with b.p. 121-124°, boiled mainly at 122-123° (3 mm) after repeated distillation: d_4^{17} 1.1300; n_D^{17} 1.4425; MR_D 52.14 [1]; calculated 51.94.

The fraction with b.p. up to 80° was separated, according to the method of Kuster and Grassner [2], into cyclopropane-1,1-dicarboxylic ester with a yield of 64.52% of theory, by saturation of the fraction with gaseous hydrogen bromide, fractional distillation of the mixture of malonic and β-brom-ethyl-malonic esters formed, and reconversion of the latter into cyclopropane-1,1-dicarboxylic acid with the help of sodium alcoholate.

SUMMARY

1. Haloid-substituted alkylmalonic esters are formed in good yields by reaction of sodium malonic ester with 1,3-, 1,5-, and 1,6-dihaloid derivatives under conditions which inhibit the side reactions, the value of which is determined by the excess of dihaloid-derivative used for the reaction, and can be calculated beforehand.

2. When sodium malonic ester and 1,2-and 1,4-dihaloid derivatives are reacted under the same conditions, β- and δ-haloidalkylmalonic esters are obtained in very poor yield, because the reaction proceeds further with the formation of cyclic polymethylene.

3. δ-Brom-α-methylamylmalonic ester is obtained by addition of HBr to α-methyl-δ-pentenylmalonic ester.

4. Upon reaction of sodium alcoholate with haloidalkylmalonic esters, a five-membered ring is formed with the greatest of ease in about 90% yield of theoretical, four-membered with a yield of about 70%, three-membered - 65%, six-membered, about 60% and seven-membered - 3%.

5. The nature of the halogen in the haloidalkylmalonic ester affects very little the yield of the cyclic ester.

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* See Consultants Bureau, translation, p. 127

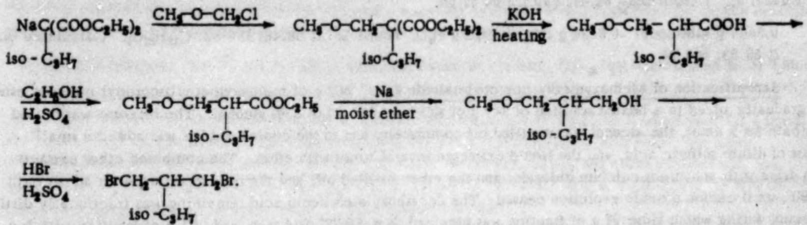
** See Consultants Bureau, translation, p. a-109

SELECTIVE MALONIC SYNTHESIS

II. REACTION OF SODIUM MALONIC ESTER WITH 4-BROM-3-BROMETHYL-2-METHYLBUTANE

V. P. Golmov and N. M. Afanasev

In the preceding articles by one of us [1,2], it was demonstrated that γ-haloidalkylmalonic ester intermediate product is obtained in good yield, up to 70% of theoretical, by reaction of sodium malonic ester with the bromide or iodide of trimethylene under the conditions favorable for good product yield. Upon reaction of sodium alcoholate with γ-haloidalkylmalonic ester, it transforms into a four-membered cyclic compound, with a yield also equal to approximately 70%. As a continuing study of the reaction of sodium malonic ester with dihaloidoderivatives, the authors in the present work have carried out an analogous reaction with 4-brom-3-bromethyl-2-methylbutane, for the purpose of determining whether or not the isopropyl group contained in the molecule of initial dibromide exerts any influence on the yield of γ-bromalkylmalonic ester, and also upon the rate of cyclization of the latter. The method selected by the authors for synthesis of the latter consisted of reacting monochlormethyl ester with the sodium derivative of isopropylmalonic ester, of transformation of the methoxymethylisopropylmalonic ester formed thereby into β-methoxy-α-isopropylpropionic acid, and of reduction of the ester of the latter (acid) into β-methoxy-α-isopropylpropyl alcohol with resulting interaction of it with a mixture of hydrogen bromide and sulfuric acid:



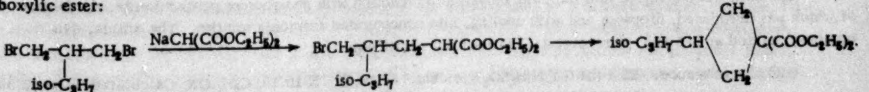
$$\underset{\text{iso-}C_3H_7}{NaC}(COOC_2H_5)_2 \xrightarrow{CH_3-O-CH_2Cl} CH_3-O-CH_2-\underset{\text{iso-}C_3H_7}{C}(COOC_2H_5)_2 \xrightarrow[\text{heating}]{KOH} CH_3-O-CH_2-\underset{\text{iso-}C_3H_7}{CH}-COOH \longrightarrow$$

$$\xrightarrow[H_2SO_4]{C_2H_5OH} CH_3-O-CH_2-\underset{\text{iso-}C_3H_7}{CH}-COOC_2H_5 \xrightarrow[\text{moist ether}]{Na} CH_3-O-CH_2-\underset{\text{iso-}C_3H_7}{CH}-CH_2OH \longrightarrow$$

$$\xrightarrow[H_2SO_4]{HBr} BrCH_2-\underset{\text{iso-}C_3H_7}{CH}-CH_2Br.$$

Execution of the above-mentioned reactions clarified the fact that the liquid β-methoxy-α-isopropylpropionic acid, ("β-methoxymethyl isovaleric") acid, obtained earlier by Simonsen [3] by the same method, in reality is a mixture of crystalline β-methoxy-α-isopropylpropionic acid (m.p. 37-38°) with unsaturated liquid α-isopropylacrylic acid, obtained earlier by Semenov via another method [4].

Upon reaction of sodium malonic ester with 4-brom-3-bromethyl-2-methylbutane, γ-brom-β-isopropylpropylmalonic ester is obtained in only 18% yield, because in the case given, even under conditions which are not favorable to cyclization, the reaction proceeds further to the formation of 1-isopropylcyclobutane-3,3-dicarboxylic ester:

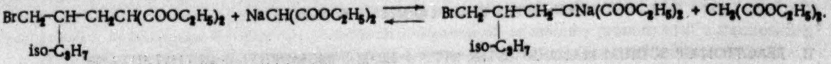


$$BrCH_2-\underset{\text{iso-}C_3H_7}{CH}-CH_2Br \xrightarrow{NaCH(COOC_2H_5)_2} BrCH_2-\underset{\text{iso-}C_3H_7}{CH}-CH_2-CH(COOC_2H_5)_2 \longrightarrow \text{iso-}C_3H_7-CH\langle{}^{CH_2}_{CH_2}\rangle C(COOC_2H_5)_2.$$

Under the same conditions, γ-iodopropylmalonic ester, for example, is obtained in a yield of 58%, and the cyclobutane-1,1-dicarboxylic ester in negligible quantity [2]. Thus the isopropyl group, contained in the molecule of original bromide, exerts a significant influence on the course of selective malonic synthesis.

Upon reaction of sodium alcoholate with the isolated γ-brom-β-isopropylpropylmalonic ester, the latter transforms into 1-isopropylcyclobutane-3,3-dicarboxylic ester, with a yield 70% of theory, which is exactly the same as γ-brom- or γ-iodpropylmalonic ester, into cyclobutane-1,1-dicarboxylic ester.

This points to the conclusion that the isopropyl group does not affect the velocity constant for four-membered ring formation, and thus explains the unusual course for the first phase of the reaction: it must be admitted that the reversible reaction between sodium malonic ester and γ-brom-β-isopropylpropylmalonic ester is shifted to the right.



$$\underset{\text{iso-}C_3H_7}{BrCH_2-\underset{|}{CH}}-CH_2CH(COOC_2H_5)_2 + NaCH(COOC_2H_5)_2 \rightleftarrows \underset{\text{iso-}C_3H_7}{BrCH_2-\underset{|}{CH}}-CH_2-CNa(COOC_2H_5)_2 + CH_2(COOC_2H_5)_2.$$

As the result, the sodium derivative of γ-brom-β-isopropylpropylmalonic ester should be formed in the reaction mixture, during the process of reaction, in increased concentration, and its cyclization should proceed more rapidly than with other γ-haloidalkylmalonic esters with a non-branched carbon chain.

EXPERIMENTAL

As initial substances for the present work served: isopropylmalonic ester, with a b.p. of 77-79° at 3 mm [5], obtained by reaction of sodium malonic ester with isopropyl iodide, and monochlormethyl ester, with a b.p. of 55-60° [6]. In view of the fact that the authors in many cases have departed from the directions contained in the work of Simonsen [3], the experimental methods are cited in full.

Methoxymethylisopropylmalonic Ester. 11.5 g (0.5 mole) of powdered metallic sodium was introduced into 300 ml of dry ether, and thereto was added 101 g (0.5 mole) of isopropylmalonic ester. During approximately one hour all of the sodium went into solution. 50 g (0.62 mole) of chlormethyl ether was then added from a dropping funnel, with water cooling, at such a speed as to avoid boiling of the ether. After 24 hours, the reaction mixture was poured into water, the ether layer separated, and the water layer extracted twice with ether. The combined ether extracts were dried by anhydrous calcium chloride, and the ether distilled off. The combined residues from six experiments gave back, upon vacuum distillation, 130 g of isopropylmalonic ester (the fraction with a b.p. of 77-80° at 3 mm) and 431 g of methoxymethylisopropylmalonic ester, boiling at 100-101° (3 mm). The yield amounted to 75.3% of theory, calculated on the basis of isopropylmalonic ester entered into reaction; d_4^{20} 1.0223; n_D^{20} 1.4320; MR_D 62.41; calculated 62.54.

0.3047 g substance: 0.6534 g CO_2; 0.2422 g H_2O. Found %: C 58.48; H 8.83. $C_{12}H_{22}O_5$. Calculated %: C 58.53; H 8.94.

Saponification of Methoxymethylisopropylmalonic Ester. 562 g of methoxymethylisopropyl malonic ester was gradually added to a heated solution of 347 g of KOH in 1200 ml of 33% alcohol. The mixture was boiled on a bath for 2 hours, the alcohol was distilled off completely, and to the cooled residue was added a small excess of dilute sulfuric acid, and the liquid extracted several times with ether. The combined ether extracts were dried with anhydrous calcium chloride, and the ether distilled off, and the residue refluxed on an oil bath at 180°, until carbon dioxide evolution ceased. The decarboxylated liquid acid remaining was fractionally distilled in vacuo, during which time 97 g of fraction was obtained, b.p. 69-72° at 4 mm, and 201 g of fraction with b.p. 103-105° at 4 mm. The latter, upon standing, crystallized completely.

α-Isopropylacrylic Acid. The 69-72° (at 4 mm) fraction upon repeated distillation boiled in the range 185-186° (708 mm) and, judging from the constants and results of elementary analysis, represented α-isopropylacrylic acid. Yield 37.2% of theoretical; d_4^{20} 0.9579; n_D^{20} 1.4336; MR_D 31.00; calculated 30.98.

0.3030 g substance: 0.7025 g CO_2; 0.2450 g H_2O. Found %: C 63.23; H 8.98. $C_6H_{10}O_2$. Calculated %: C 63.16; H 8.77.

The acid was converted into the chloranhydride by reaction with phosphorous pentachloride, the former of which was introduced, dropwise and with cooling, into concentrated ammonia solution. The amide, thus obtained, melted at 104-105° after recrystallization from chloroform.

0.2539 g substance: 22.1 ml 0.1 N H_2SO_4 Kjeldahl. Found %: N 12.19. $C_6H_{11}ON$. Calculated %: N 12.30.

The ethyl ester of α-isopropylacrylic acid was obtained by heating on a water bath for 4 hours with triple the volume of absolute alcohol, to which was added 10% by volume of concentrated sulfuric acid. With heating terminated, the mixture was poured into water, extracted with ether, ether extraction washed with water, dried with $CaCl_2$, the ester distilled off, and the residue redistilled at 149-152° (710 mm). Yield 78.8% of theoretical; d_4^{20} 0.8950; n_D^{20} 1.4210; MR_D 40.23; calculated 40.33.

0.1996 g substance: 0.4941 g CO_2; 0.1783 g H_2O. Found %: C 67.52; H 9.93. $C_8H_{14}O_2$. Calculated %: C 67.61; H 9.86.

As evidence for unsaturation, bromine was added to the acid. 6.3 g (0.055 mole) of the acid was dissolved in 30 ml of dry ether, and to the solution was added, dropwise, with water cooling, 10 g (0.062 mole) of bromine. After 4 hours, the reaction mixture was poured into water, agitated with a solution of Na_2CO_3 to the point of discoloration, the ether layer separated, dried with $CaCl_2$, and the ether distilled off. The residue crystallized almost completely upon standing. The crystals were sucked off, and after recrystallization from chloroform, melted at 88-89°. Yield 14 g, or 62.7% of the theoretical.

0.3150 g substance: 0.4325 g AgBr. Found %: Br 58.76. $C_6H_{10}O_2Br_2$. Calculated %: Br 58.39.

For addition of bromine to the ethyl ester of α-isopropylacrylic acid, 10 g of the latter was dissolved in 40 ml of dry ether, and to the solution was added dropwise, and with cooling, 12 g of bromine. After treatment, according to the preceding, an oil was obtained with a b.p. of 98-100° at 4 mm, representing the ethyl ester of α,β-dibrom-α-isopropylpropionic acid; d_4^{20} 1.5751; n_D^{20} 1.5751; n_D^{20} 1.4975; MR_D 56.14; calculated 56.33.

0.3415 g substance: 0.4231 g AgBr. Found %: Br 53.00. $C_8H_{14}O_2Br_2$. Calculated %: Br 52.98.

β-Methoxy-α-isopropylpropionic Acid. The 103-105° (4 mm) fraction, obtained as the result of saponification of methoxymethylisopropylmalonic ester, was found to be β-methoxy-α-isopropylpropionic acid (yield 60.5%). After recrystallization from ether, it appeared as large, colorless crystals, melting at 37-38°; d_4^{40} 0.9911; n_D^{40} 1.4242; MR_D 37.60; calculated 37.70.

0.1964 g substance: 0.4132 g CO_2; 0 1673 g H_2O. Found %: C 57.38; H 9.46. $C_7H_{14}O_3$. Calculated %: C 57.53; H 9.58.

8 g of the acid was added to 12 g of PCl_5, and the liquid mixture formed was fractionated. The chloranhydride of β-methoxy-α-isopropylpropionic acid (b.p. 148-151°; d_4^{20} 1.0226; n_D^{20} 1.4307; MR_D 41.62; calculated 41.42) was dissolved in ether, which was saturated with ammonia and in addition the solution was saturated with NH_3; the ether solution was steamed off to dryness, and the residue extracted with chloroform; the amide obtained from the chloroform solution melted at 113° after recrystallization from water.

0.1101 g substance: 7.4 ml 0.1 N H_2SO_4 (Kjeldahl). Found %: N 9.41. $C_7H_{15}O_2N$. Calculated %: N 9.65.

For esterification, 226 g of β-methoxy-α-isopropylpropionic acid was added to a solution of 62 ml of H_2SO_4 (specific gravity 1.84) in 620 ml of absolute alcohol. The mixture was boiled on a water bath for 4 hours, then was poured into 2 liters of water, the ester separated, the water layer extracted with ether, the ether extract combined with the main product, washed with water, dried with $CaCl_2$, the ether distilled off, and the residue redistilled in vacuo, at which time it boiled at 35 mm in the 95-97° range, yield 236 g, or 90% of the theoretical; d_4^{20} 0.9332; n_D^{20} 1.4180; MR_D 46.98; calculated 47.06.

0.1846 g substance: 0.4196 g CO_2; 0.1744 g H_2O. Found %: C 61.69; H 10.49. $C_9H_{18}O_3$. Calculated %: C 62.07; H 10.35.

Upon saponification of the β-methoxy-α-isopropylpropionic acid ester, there is obtained a mixture of β-methoxy-α-isopropylpropionic acid and α-isopropylacrylic acid of approximately the same composition as upon saponification of methoxymethylisopropylmalonic ester.

β-Methoxy-α-isopropylpropyl Alcohol. The authors applied the method of Prins [7] for reduction of the ethyl ester of β-methoxy-α-isopropylpropionic acid. Into a flask equipped with dropping funnel, mechanical stirrer, and thermometer reaching almost to the bottom of the flask, cooled by a salt-ice mixture, 150 ml of a saturated solution of sodium acetate and 70 g (0.4 mole) of β-methoxy-α-isopropylpropionic acid ethyl ester, dissolved in 210 ml of diethyl ether, was added. 56 g (2.4 g-atoms) of metallic sodium was gradually added, with slow mixing, to the mixture at a temperature of −8 to −3°, and 30% acetic acid dropwise, simultaneously. Total addition took about 10 hours. Water was then added to dissolve the precipitated salt, the ether was separated, and the water layer twice extracted with ether. The combined ether solutions were dried with anhydrous potash, the ether distilled off, and the residue fractionated in vacuo, and the fraction collected boiled at 92-94° (38 mm). A considerable quantity of brownish viscous mass remained in the flask. To purify from the admixture of initial ester, the alcohol obtained was boiled with caustic potash solution, then salted out with potash, the separated layer set aside, the water layer extracted with ether, the ether extract dried with anhydrous potash, and the ether distilled off. Upon distillation in vacuo, the residue boiled at 91-93° (26 mm), and represented pure β-methoxy-α-isopropylpropyl alcohol, in the form of an oily liquid, turning yellow rapidly in the air, possessing a characteristic camphor odor, and quite soluble in water. From 236 g of initial ester, 90 g of β-methoxy-α-isopropylpropyl alcohol was obtained, i.e., 50.5% of the theoretical yield; d_4^{20} 0.9112; n_D^{20} 1.4322; MR_D 37.59; calculated 37.69.

0.2271 g substance: 0.5302 g CO_2; 0.2472 g H_2O. Found %: C 63.67; H 12.10. $C_7H_{16}O_2$. Calculated %: C 63.64; H 12.14.

The p-nitrobenzoate of β-methoxy-α-isopropylpropyl alcohol, obtained by the usual procedure of reaction of p-nitrobenzoyl chloride with alcohol in pyridine, melted at 236-237° after recrystallization from alcohol.

4-Brom-3-brommethyl-2-methylbutane. 76 g of β-methoxy-α-isopropylpropyl alcohol was mixed with 380 g of hydrobromic acid (d. 1.54), and to the mixture was next added 120 ml of sulfuric acid (d. 1.84), and the liquid boiled for 6 hours on an oil bath. During the same period, the mixture became intensely dark. After cooling, the liquid was poured into water, carefully agitated (vigorous agitation causes formation of a very stable emulsion), the lower bromide layer separated, and the upper extracted 4 times with ether. The ether extracts, combined with the main bulk product, were washed with soda solutions, then with water, dried with $CaCl_2$, the ether distilled off, and the residue redistilled in vacuo. Upon distillation, we obtained 82 g of heavy oily liquid, becoming brownish upon exposure to air, and having a b.p. of 82-84° at 9 mm. For purification, the bromide obtained was shaken twice with half the volume of concentrated sulfuric acid, then washed with water, dried with $CaCl_2$, and redistilled in vacuo. Purified in this manner, the 4-brom-3-brommethyl-2-methylbutane was in the form of a colorless heavy liquid of characteristic odor, with a b.p. of 90° at 13 mm. Yield 58.9% of theoretical; d_4^{20} 1.6132; n_D^{20} 1.5076; MR_D 45.44; calculated 45.07.

0.3977 g substance; 0.4328 g CO_2; 0.1840 g H_2O. 0.3091 g substance: 0.4762 g AgBr. Found %: C 29.68; H 5.14; Br 65.61. $C_6H_{12}Br_2$. Calculated %: C 29.51; H 4.92; Br 65.57.

Reaction of Sodium Malonic Ester with 4-Brom-3-brommethyl-2-methylbutane. 109 g (0.68 mole, 4 times the theoretical) of malonic ester was added to an alcoholate solution, prepared from 3.95 g (0.17 g-atom) of metallic sodium and 50 ml of absolute alcohol, followed by 85 g (0.34 mole) of 4-brom-3-brommethyl-2-methylbutane. The mixture was heated to boiling on a bath for 4 hours, after which the reaction became neutral. After cooling, the reaction mixture was poured into 400 ml of water, the reaction products separated, and the water layer extracted twice with ether. The ether extracts combined with the principal mass of product, were washed with water, dried with anhydrous calcium chloride, and the ether distilled off afterwards, and the residue fractionated in vacuo at 6 mm. From this there was obtained 138 g of fraction with b.p. 76-78° (a mixture of malonic ester with the initial dibromide), 9.5 g with b.p. 115-117° (1-isopropylcyclobutane-3,3-dicarboxylic ester —yield 46.1% of theoretical), 10 g with b.p. 154-158° (γ-brom-β-isopropylpropylmalonic ester, yield 18.2% of theoretical) and 10 g of residue, probably representing the ethyl ester of 3-isopropylpentane-1,1,5,5-tetracarboxylic acid.

1-Isopropylcyclobutane-3,3-dicarboxylic ester was a colorless liquid, almost without odor; d_4^{20} 0.9966; n_D^{20} 1.4374; MR_D 63.67; calculated 63.80.

0.1771 g substance: 0.4177 g CO_2; 0.1434 g H_2O. Found %: C 64.32; H 9.00. $C_{13}H_{22}O_4$. Calculated %: C 64.46; H 9.09.

The 154-158° fraction, upon repeated distillation in vacuo, boiled at 155-156°, and was in the form of a slightly yellowish liquid with an odor of haloidalkylmalonic ester; d_4^{20} 1.2088; n_D^{20} 1.4623; MR_D 73.50; calculated 73.31.

The substance gave a positive Beilstein test for halogen.

0.2571 g substance: 0.4584 g CO_2; 0.1676 g H_2O. 0.3914 g substance: 0.2179 g AgBr. Found %: C 48.62; H 7.24; Br 23.70. $C_{13}H_{23}O_4Br$. Calculated %: C 48.30; H 7.12; Br 24.73.

Cyclization of γ-Brom-β-isopropylpropylmalonic Ester. 1 g (0.04 g-atom) of metallic sodium was dissolved in 49 ml of absolute alcohol, and 13 g (0.04 mole) of γ-brom-β-isopropylpropyl malonic ester was added to the alcoholate solution after its cooling. The mixture was boiled on a bath for several hours, until the sodium derivative of the initial bromester, precipitated in the beginning, was dissolved. Subsequently, the reaction mixture was cooled, poured into water, the reaction product extracted with ether, washed with water, dried with $CaCl_2$, and the ether distilled off. Upon distilling in vacuo, 5.9 g of 1-isopropylcyclobutane-3,3-dicarboxylic ester was obtained, with a b.p. of 118-120° at 7 mm, and 1.9 g of initial bromester was recovered. The yield of cyclic product was 70.2% of the theoretical, based upon γ-brom-isopropylpropylmalonic ester used. The residue in the flask weighed 1 g.

1-Isopropylcyclobutane-3,3-dicarboxylic Acid. To a warm solution of 42 g of caustic potash in 150 ml of 95% alcohol, was added 58 g of 1-isopropylcyclobutane-3,3-dicarboxylic ester. At the same time a large amount of precipitate separated out, which was dissolved upon addition of 25 ml water. After 2 hours heating on a bath at the boiling point of the liquid, 125 ml of water was added, and the alcohol distilled off completely. The cooled residue was acidified with dilute (1:1) sulfuric acid and extracted 7 times with ether. The ether extract was dried with calcium chloride, and after distilling off the ether, 41.5 g (93.1%) of crystalline acid was left, which, after being recrystallized three times from benzene, was obtained in the form of colorless flakes, melting at 168°.

0.1758 g substance: 0.3726 g CO_2; 0.1207 g H_2O. Found %: C 57.81; H 7.63. $C_9H_{14}O_4$. Calculated %: C 58.06; H 7.53.

The Diamide of 1-Isopropylcyclobutane-3,3-dicarboxylic Acid was obtained, according to the method of Demyanov and Telnov [8] by reaction of a concentrated solution of ammonia with 1-isopropylcyclobutane-3,3-dicarboxylic ester at normal temperature for one month. After recrystallization from water, the obtained amide melted with decomposition at 211°.

0.2522 g substance: 27.0 ml 0.1 N H_2SO_4 (Kjeldahl.) Found %: N 14.99. $C_9H_{16}O_2N_2$. Calculated %: N 15.21.

SUMMARY

1. When sodium malonic ester is reacted with 4-brom-3-brommethyl-2-methylbutane, contrary to γ-brompropyl- and γ-iodopropylmalonic ester, there is formed the γ-brom-β-isopropylpropylmalonic ester with a yield of only 18% of the theoretical, because in this instance the reaction goes further, with the formation of 1-isopropylcyclobutane-3,3-dicarboxylic ester as the principal product.

2. A branched chain in the γ-brom-β-isopropylpropylmalonic ester molecule does not affect the rate of cyclization of the latter; upon its reaction with sodium alcoholate, it transforms into a four-membered cyclic compound with a yield 70% of theory, i.e., approximately the same as the other γ-haloidalkylmalonic esters, that have been studied up to the present time.

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ISOMERISM OF ALLENE HYDROCARBONS UNDER THE INFLUENCE OF SILICATES

IX. ISOMERISM OF HEXADIENE-1,2

Ya. M. Slobodin

In 1885, A. E. Favorsky [1] proposed a mechanism for the isomeric transformation phenomenon of the hydrocarbon series C_nH_{2n-2}, from which resulted the rule that monosubstituted acetylenes transform into disubstituted acetylenes via the corresponding allene forms. These schemes did not foresee the transformation of cumulative dienes into conjugated dienes. Later, A. E. Favorsky considered these reactions to be intramolecular regroupings, where alcoholic alkali functions in the role of catalyst [2].

The isomerism of allene hydrocarbons is thought to take three courses: 1) transformation into monosubstituted acetylenes, 2) transformation into disubstituted acetylenes and 3) transformation into conjugated dienes.

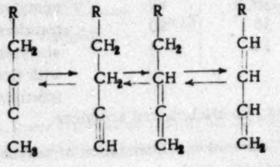
Transformation of allenes into monosubstituted acetylenes occurs easily upon heating with metallic sodium. In this case the process is not reversible, due to the fact that the monosubstituted acetylene formed is derived from the reaction sphere in the form of its sodium derivative [1-3]. The authors, applying floridin as the catalyst, have proved the reversibility of these transformations in the case of allene and allylene [4], methylallene and ethylacetylene [5], asymmetrical dimethylallene and isopropylacetylene [6], and others. The data obtained by us for equilibrium in the allene-allylene system were found to be of the same order as the theoretical calculations, based upon spectroscopic data [7]. Still earlier, Kucherov [8] and Favorsky and Debu [9] observed the transformation of asymmetrical dimethylallene into isopropylacetylene.

The transformation of allenes into disubstituted acetylenes, as well as formation of the latter from monosubstituted acetylenes, has been observed frequently. This draws attention to the fact that in a majority of cases, upon transformation of monosubstituted acetylenes into disubstituted acetylenes, it is not possible to detect the corresponding allenes, which are thought to be intermediate forms, although their stability is sufficient for at least partial existence under the conditions of the reaction [14-17].

On the other hand, in a majority of the cases, when the principal products of transformation of the monosubstituted acetylenes are found to be allenes, it is not possible, as a rule, to find disubstituted acetylenes in the reaction mixture [18]. In addition, when allenes are transformed into disubstituted acetylenes, it is always possible to detect among the reaction products smaller or larger quantities of the monosubstituted acetylenes.

A review of the literature data indicates that the allenes are more regularly transformed into conjugated dienes [10-13]. This also follows from energy considerations [19-20].

On the basis of investigations of transformations of hydrocarbons of the series C_nH_{2n-2} in the presence of silicate, we [21-22] have expressed an assumption that the process of isomerism for monosubstituted acetylenes should be divided into two independent processes. The first one consists in transformation of monosubstituted acetylenes into conjugated dienes, through the intermediate allene forms. The second process, independent of the first, consists of transformation of monosubstituted acetylenes directly into disubstituted acetylenes:



Proof of the reversibility of transformations of the separate systems of this general scheme has been obtained on a sufficient variety of compounds.

In the present investigation, the transformation of hexadiene-1,2 in the presence of floridin and of chromic oxide has been studied. In the combined dispersion spectrum of the initial hydrocarbon intense lines are observed with frequencies of 1039, 1096 and 1129 centimeter^{-1}, which characterize the allene grouping. Lines in the frequency interval 1600-1700 centimeter^{-1}, which characterize double bonds, are completely absent. A very faint line was detected with a frequency of 2234 centimeter^{-1}, indicating the presence of small amounts (less than 10%) of disubstituted acetylene in the hydrocarbon.

In the combined dispersion spectrum of allene isomerized in the presence of floridin, frequencies of 1039, 1096 and 1129 centimeter $^{-1}$ were weakened. Lines with frequencies 1655 and 1668 centimeters^{-1}, characterizing double bonds, appeared. Moreover, there appeared lines with frequencies of 2123, 2237 and 2303 centimeter^{-1}. The frequency, 2123 centimeter^{-1}, points to the presence of monosubstituted acetylene in the hydrocarbon mixture after isomerization in the presence of floridin. The frequencies, 2237 and 2303 centimeter^{-1} indicate disubstituted acetylene in the isomerized hydrocarbon. Moreover, the frequency of 2303 centimeter^{-1} and the doublet of 1302-1330 centimeter $^{-1}$ indicate that the acetylene contains the grouping $CH_3-C\equiv C-$. The absence of the 2247 centimeter $^{-1}$ frequency can be considered as proof that there is not formed hexyne-3 in noticeable quantity when hexadiene-1,2 is isomerized in the presence of floridin.

A visual evaluation of the spectral line intensities indicates that the hydrocarbon mixture obtained upon isomerization of hexadiene-1,2, in the presence of floridin at 230°, contains about 50% unchanged allene, 20% conjugated diene, the same of disubstituted allene, and about 10% of monosubstituted acetylene. At 280° the content of unchanged allene drops to 20% and the content of conjugated diene increases to 50%. The monosubstituted and disubstituted acetylene contents are practically unchanged.

The data obtained affirm the assumption that the formation process of the diene is not correlated with the formation process of acetylenes. Each of these transformations occurs at its own speed, and, diversely, depends upon the temperature conditions of the process.

Isomerization of hexadiene-1,2 in the presence of chromic oxide at 250° proceeds somewhat differently. Attention is drawn to the relatively high intensity of frequencies for the monosubstituted acetylene combinations, which exceeds the frequency intensity of disubstituted acetylene. It is necessary to note that in the combined dispersion spectrum of the hydrocarbon, isomerized with chromic oxide, there is, moreover, a frequency of 2094 centimeter^{-1}, the intensity of which is equal to the frequency intensity of 2125 centimeter^{-1}. This frequency points to the presence of an additional constituent. After passing one and the same portion of allene three times through a tube with chromic oxide at 250°, an intensification of the 2094 centimeter^{-1} frequency was observed. This problem was not studied in detail.

On the basis of intensity comparisons of the frequencies of the combinations, it could be assumed that the hydrocarbon formed after a single passage of the allene over chromic oxide, contained about 65% of unchanged allene, about 15% of conjugated diene, as much of the monosubstituted acetylene, and about 5% of disubstituted acetylene. The data obtained are compiled in Table 1.

TABLE 1

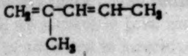
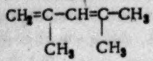
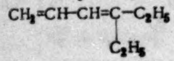
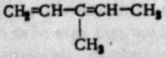
Catalyst	Temp. of the experiment	Content (in %)			
		Allene	Conjugated diene	Acetylene	
				Mono-substituted	Disubstituted
Floridin	230°	50	20	10	20
Floridin	280	20	50	10	20
Chromic oxide	250	65	15	15	5

Experiments with chromic oxide indicated that the initial products of allene isomerization appear to be conjugated diene and monosubstituted acetylene. The latter transforms into disubstituted acetylene. In experiments with floridin, the monosubstituted acetylene was present only in small quantity. Its main mass transformed into disubstituted acetylene.

The work of Levina, Viktorova and Eykhfeld [17], devoted to isomerization of hexyne-1 over chromic catalyst, noted the ease with which this hydrocarbon transforms. In the isomerized hydrocarbon, the authors found disubstituted acetylene and conjugated diene. Of the disubstituted acetylenes, according to their opinion, there can be present in the mixture both hexyne-2 and hexyne-3. The latter, in particular, is affirmed by the presence in the spectrum of the frequency, 2249 centimeter $^{-1}$. The conjugated diene was demonstrated by the authors from its combination product with maleic anhydride. It was found to be hexadiene-2,4.

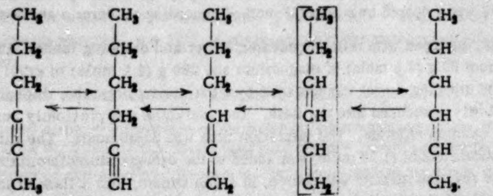
To determine the nature of the conjugated diene formed in our experiments, the combined dispersion spectra of a series of conjugated dienes were taken. It was found that only in the case of the hexdiene-2,4 spectrum are there intensive lines with frequencies of 1655 and 1668 centimeter $^{-1}$. Not one of the 1,3-dienes examined contained in its spectrum a line with the frequency 1668 centimeter $^{-1}$. These data are compiled in Table 2.

TABLE 2

Hydrocarbons	Frequencies of the double bonds (in cm^{-1})
$CH_2=CH-CH=CH-CH_3$	1596 (4), 1603 (4), 1646 (10), 1655 (10)
$CH_3-CH=CH-CH=CH-CH_3$	1600 (3), 1655 (10), 1668 (6)
 $CH_2=\underset{CH_3}{C}-CH=CH-CH_3$	1605 (5), 1659 (10)
 $CH_2=\underset{CH_3}{C}-CH=\underset{CH_3}{C}-CH_3$	1600 (1), 1628 (5), 1645 (5), 1657 (5)
 $CH_2=CH-CH=\underset{C_2H_5}{C}-C_2H_5$	1591 (3), 1645 (10)
 $CH_2=CH-\underset{CH_3}{C}=CH-CH_3$	1586 (3), 1609 (5), 1645 (10)

In Table 3 are quoted, for comparison, the combined dispersion spectra for the initial allene, the allene isomerized over floridin at 280°, and the spectrum of hexadiene-2,4. The latter was obtained by regeneration of its crystalline tetrabromide, with a m.p. of 181-182°, and boiled at 82°. As can be seen from the data in Table 3, all of the frequencies of both allene and of hexadiene-2,4 are contained in the spectrum of the isomerized hydrocarbon. Moreover, in the spectrum there is a series of frequencies corresponding to the acetylenes.

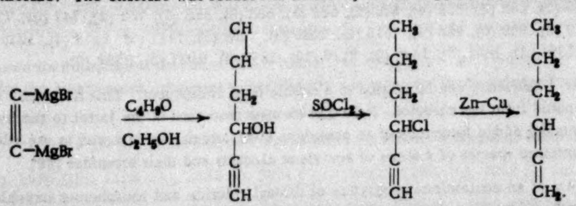
On the basis of the scheme stated, the isomerization of hexadiene-1,2 over floridin can be presented in the following manner:



Transformation of hexadiene-1,3 into hexdiene-2,4, on floridin, proceeds very readily.

Hexadiene-1,2 was prepared by the general method worked out by Ginsburg [23].*

Hexyn-1-ol-3, required for the synthesis, was derived from dimagnesium-dibromacetylene by reaction with an equimolecular mixture of butyraldehyde and absolute alcohol [24-25]. The derived carbinol was converted into the corresponding acetylene chloride by reaction with a mixture of thionyl chloride and phosphorous oxychloride. The chloride was reduced to allene by a zinc-copper couple in absolute alcohol.



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* Recently hexadiene-1,2 was synthesized [26] by an analogous method. On the basis of an infrared absorption study, the authors demonstrated that the hydrocarbon also contained some acetylenic hydrocarbon component.

TABLE 3

Hexadiene-1,2	Isomerized hydrocarbon	Hexadiene-2,4 [28]
371 (2)	371 (5)	
407 (1)	410 (1)	
	435 (1)	432 (3)
	463 (1)	463 (2)
	478 (1)	
	513 (2)	
533 (2)	538 (2)	816 (1)
835 (3)	833 (1)	831 (1)
847 (3)	855 (1)	
891 (2)	887 (3)	
932 (1)		923 (1)
954 (2)		
996 (1)	998 (1)	
1039 (5)	1039 (4)	1034 (3 w)
1096 (10)	1096 (2)	
1129 (10)	1129 (1)	
	1158 (1)	1150 (6)
	1172 (1)	1167 (6)
1220 (5)	1225 (1)	
	1259 (1)	1239 (8)
		1278 (3)
1293 (2)		
	1302 (2)	1302 (6)
	1330 (1)	
	1351 (1)	
	1382 (5)	1376 (5)
1441 (10 w)	1437 (6)	
	1449 (6)	1449 (5)
		1552 (1)
	1600($^1/_2$)	1600 (3)
	1655 (8)	1655 (10)
	1668 (4)	1668 (6)
	2123 (1)	
2234 (0)	2237 (6)	
	2303 (3)	
		2858 (2)
2877 (3)	2872 (2)	2880 (2)
2908 (3)	2917 (4)	2915 (5 w)
2938 (3)	2938 (3)	
2990 (10)	2990 (3)	2992 (1)

EXPERIMENTAL

Hexyne-1-ol-3. The carbinol was prepared by a general method according to Teterin and Ivanov [24].

In a three-necked round flask, equipped with reflux condenser, stirrer and dropping funnel, ethyl magnesium bromide was prepared from 60 g (2.5 mole) of magnesium and 280 g (2.5 mole) of ethyl bromide. After completion of the reaction, the dropping funnel was replaced by a gas-conducting tube, through which acetylene, from a gasometer, was slowly introduced into the flask. The acetylene was previously purified by the usual procedure, and dried with calcium chloride. The saturation time was 35-40 hours. The mixture of butyraldehyde (1.25 mole) and absolute alcohol (1.25 mole) was added to the dimagnesiumdibromacetylene formed. After standing 12 hours, the reaction mixture was poured, in a thin stream, into a flask of ice water, followed by a dilute hydrochloric acid solution until the precipitate of basic magnesium salt dissolved. The upper oily layer was separated. The water solution was extracted several times with ether. The solutions were dried over potash and distilled. The crude carbinol boiled at 135-143°. After several distillations, a fraction was separated with a b.p. of 140-141°, corresponding to hexyne-1-ol-3. Yield was 20-25% of theory.

d_4^{20} 0.8707; n_D^{20} 1.4334; MR_D 29.35; calculated 29.43.

Combined dispersion spectrum:

176 (5), 223 (2), 249 (3), 285 (3), 352 (4), 533 (2), 583 (3), 633 (3), 663 (3), 703 (2), 747 (2), 774 (2), 806 (3), 845 (2), 870 (2), 909 (5), 988 (2), 1013 (2), 1039 (3), 1068 (5), 1111 (5), 1153 (4), 1215 (3), 1295 (6), 1334 (3), 1391 (3), 1451 (8), 1642 (2), 2116 (10), 2872 (4), 2921 (5), 2968 (3).

The 1642 centimeter^{-1} frequency can be related to a double bond component. This frequency is also retained in the chloride prepared from the carbinol. It disappears upon reduction of the latter to the hydrocarbon. It is possible that it represents the added frequency of an acetylene bond, which was detected in the 1600-1700 centimeter^{-1} region of the infrared spectra of a series of acetylene alcohols and their bromides [29].

3-Chlorhexyne-1. 54 g of an equimolecular mixture of thionyl chloride and phosphorous oxychloride was placed in a flask equipped with reflux condenser. The flask was cooled with ice water. From a dropping funnel was slowly poured a mixture of 20 g of hexynol and 16 g of pyridine. After termination of reaction, the mixture was diluted with water. The chloride formed was distilled off with steam. The yield of chloride was about 15% of theory. In the following experiments, the chlorinating mixture was diluted with 50 ml of ether. The yields of chloride increased to 50% of the theoretical. The crude chloride distilled at 60-62° (100 mm).

d_4^{20} 0.9198; n_D^{20} 1.4374; MR_D 33.19; calculated 33.09.

The combined dispersion spectrum:

178 (6), 225 (2), 269 (2), 354 (2), 453 (4), 608 (2), 648 (4), 688 (2), 730 (2), 1025 (2), 1108 (5), 1150 (2), 1170 (2), 1208 (3), 1300 (2), 1328 (2), 1441 (4), 1455 (4), 1645 (2), 2125 (10), 2877 (2), 2910 (2), 2936 (2), 2970 (2).

Hexadiene-1,2. A zinc-copper couple was first prepared. For this purpose, 60 g of zinc dust was treated several times with 3% hydrochloric acid solution, rinsed with distilled water, further treated, twice, with 2% copper sulfate solution, again rinsed several times with distilled water, then 96% alcohol, and finally with absolute alcohol. The prepared zinc-copper couple was washed down into the reaction flask with absolute alcohol.

Reaction was carried out in a three-necked round flask equipped with reflux condenser, stirrer and dropping funnel. The reflux condenser was filled with hot water and the hydrocarbon formed during the reaction, and the alcohol in part, not being condensed in the reflux, passed into a spiral coil well-cooled with ice water, to be collected in a receiver. The chloride was condensed in the hot cooler and was practically separated from the hydrocarbon fraction. 21 g of the hydrocarbon was obtained from 40 g of chloride, which amounted to about 75% of theory yield. A hexadiene-1,2 fraction was separated after several distillations over sodium, b.p. 74.4-74.8°.

d_4^{20} 0.7233; n_D^{20} 1.4269; MR_D 29.11; $C_6H_{10}\ulcorner_2$. Calculated: MR_D 28.97.

The combined dispersion spectrum of the hydrocarbon is quoted in Table 3. From the data in this table it can be seen that the hydrocarbon represents almost pure allene, which contains no ethylenic hydrocarbon components. Disubstituted acetylene impurity was negligible.

Isomerization of Hexadiene-1,2. a) Isomerization over Floridin. The isomerization was carried out under the conditions described earlier by the authors. The reaction tube was of transparent quartz with a diameter of 10 mm; the length of the catalyst layer was 16 cm. The floridin was activated by the usual procedure. Temperatures of the experiments were 230 and 280°. Condensate after the tests was colorless. There was negligible amount of polymers.

The hydrocarbon isomerized at 230° distilled in a wider range (74-78°); n_D^{20} 1.4245.

The combined dispersion spectrum of the hydrocarbon isomerized at 230° differed from the combined dispersion spectrum of the hydrocarbon isomerized over floridin at 280° only by frequency intensities. Therefore we quote here a group of characteristic frequencies for allene, conjugated diene, and acetylenes:

1039 (4), 1096 (10), 1129 (8), 1655 (4), 1668 (3), 2125 (1), 2237 (5 w), 2305 (2) cm^{-1}.

The hydrocarbon isomerized at 280° was also in the form of a colorless liquid with n_D^{20} 1.4225, which boiled within a still wider range (74-82°). Negligible residue was left in the distilling flask. The combined dispersion spectrum of the hydrocarbon isomerized at 280° is given in Table 3.

b) Isomerization over Chromic Oxide. The catalyst was prepared by precipitation of chromium nitrate with ammonia [27]. The experiments were conducted in the same tube as the experiments with floridin. Temperature was 250°. The condensate, after isomerization was colorless, and distilled in the range 74-77°; n_D^{20} 1.4249. The residue in the distilling flask was negligible.

In the combined dispersion spectrum of the isomerized hydrocarbon all frequencies were detected that were observed for the hydrocarbon isomerized over floridin. In addition, there appeared a new frequency of 2094 centimeter $^{-1}$.

Herein is quoted a group of characteristic frequencies for allene, conjugated diene and acetylene:

1039 (5), 1096 (10), 1129 (10), 1659 (2), 2094 (1), 2116 (1), 2237 ($^1/_2$), 2305 (0) cm^{-1}.

After the same hydrocarbon sample was passed three times through a tube with chromic oxide, at 250°, the condensate was somewhat green in color. A very small quantity of polymers was found. Of all multiple combination frequencies in the combined dispersion spectrum, the most intensive was found to be the frequency of 2094 centimeter $^{-1}$.

SUMMARY

1. It was demonstrated that, upon contact with floridin, hexadiene-1,2 isomerizes into a hydrocarbon mixture containing allene, conjugated diene, monosubstituted diene and disubstituted acetylene.

2. The primary products of isomerization of allene are found to be the conjugated diene and the monosubstituted acetylene. The disubstituted acetylene is found to be a secondary product and is formed directly from the monosubstituted acetylene.

3. On the basis of spectroscopic data, it can be assumed that disubstituted acetylene contains as one of the substitutents the methyl group, i.e., is found to be hexyne-2.

4. The conjugated diene, formed by isomerization of hexadiene-1,2 over floridin, is found to be hexadiene-2,4.

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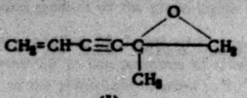
* See Consultants Bureau English translation page 265

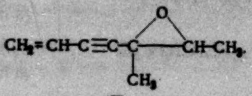
THE INTERACTION OF α-OXIDES OF THE VINYLACETYLENE SERIES WITH OXYGEN-CONTAINING AND ORGANO-MAGNESIUM COMPOUNDS. II

F. Ya. Perveev and N. I. Kudryashova

The authors [1] established earlier that the yields of condensation products of α-oxides in the vinylacetylene series with ketones depends on the nature of the catalysts and upon the reacting ketone structure, as well as upon the structural peculiarities of the oxides. At the same time it was observed that disubstituted oxides of asymmetrical structure (I) enter into reaction with ketones and aldehydes more vigorously than the trisubstituted (II):



(I)



(II)

In addition, it was noticed that the more branched the chain near the carbonyl group of the reacting ketone, the smaller is the yield of condensation products—the dioxolanes.

It was of interest to clarify whether or not this dependence will be preserved upon interaction of oxides with alcohols. And, further, we have considered it necessary to investigate the influence of catalyst nature upon the yield and rate of formation of the monoethers of glycols, as well as on the order of alcohol linkage, pertaining to which subject there is but a negligible number of works.

As the subject of investigation, we took the oxides of 2-methyl-epoxy-1,2-hexenen-5-yn-3 [I] and 3-methyl-epoxy-2,3-hepten-6-yne-4 [II], and their condensations were carried out with methyl, propyl, isopropyl, n-butyl, iso-butyl, sec-hexyl and mercyl alcohols and phenol, at which time were examined the effects of alkali (NaOH and $Ba(OH)_2$) and acid catalysts (sulfuric and oxalic acids).

The interaction of oxides with alcohols in the presence of H_2SO_4 was carried out in the following manner: the oxide was added gradually to 3 times the excess of corresponding alcohol, in the presence of 2-8 drops of H_2SO_4, in such a manner that the temperature of the reaction mixture did not exceed 45°. The solution in all cases turned to a dark-brown color. After addition of excess soda, the reaction mixture was stirred to the point of complete discoloration. In the presence of oxalic acid, the oxide was added to the boiling alcohol solution, and considerably larger amount of catalyst (4-5 g) was taken.

The addition reaction of the alcohols to α-oxides of the vinylacetylene series goes very rapidly in the presence of sulfuric acid, and with large heat evolution; reaction is practically terminated within 15-17 minutes. The disubstituted oxide of asymmetrical structure (I) reacts with alcohols more vigorously than the oxide (II). A very noticeable difference in the rate of alcohol addition is observed when alkaline catalysts are present. Thus, for example, upon interaction of oxide (I) with methyl alcohol, reaction was terminated at 3.5 hours, with a yield of 73%, while at the same time, in the case of oxide (II) reaction did not end (some non-reacted oxide remained) even after 35-40 hours of heating, and the yield of condensation products reached only 30%.

In the case of alkaline catalysts, the synthesis of glycol monoethers was carried out in the following manner: 0.4 g of metallic Na, or 0.8 g of NaOH, or 1 g of $Ba(OH)_2$ was added to 1 mole of the corresponding alcohol. The solution was heated in a round-bottomed flask with a reflux condenser to 60-80°, and into it was poured the oxide.

The glycol monoethers are represented by colorless, mobile, liquids, with a weak, almost non-characteristic odor, with the exception of the methyl ether oxide of 3-methyl-epoxy-2,3-hepten-6-yn-4, which possessed a faint, pleasant odor. The monoethers become yellow on standing in air in the absence of antioxidants, and gradually polymerize, forming viscous, gummy liquids, which, over a period of 1.5-2 months, transform into a hard, vitreous

No.	Catalyst	Formula	B.p.	n_D^{20}	d_4^{20}	MR_D		Yield
						found	calc.	(%)
1	H_2SO_4 $(COOH)_2$	$CH_2=CH-C\equiv C-C(CH_3)(OCH_3)CH_2OH$	76-77 (4 mm)	1.4860	0.9840	40.9	39.8	81
2	Na, NaOH	$CH_2=CH-C\equiv C-C(CH_3)(OH)CH_2OCH_3$	69-70 (3 mm)	1.4802	0.9644	41.3	39.8	73
3	$(COOH)_2$	$CH_2=CH-C\equiv C-C(CH_3)(OC_3H_7)CH_2OH$	93-95 (7 mm)	1.4764	0.9430	50.4	49.2	58
4	Na	$CH_2=CH-C\equiv C-C(CH_3)(OH)CH_2OC_3H_7$	91-92 (7 mm)	1.4691	0.9280	50.5	49.2	63
5	H_2SO_4	$CH_2=CH-C\equiv C-C(CH_3)(OC_4H_9)CH_2OH$	94-95 (3 mm)	1.4748	0.9304	55.0	53.7	79
6	Na	$CH_2=CH-C\equiv C-C(CH_3)(OH)CH_2OC_4H_9$	89-90 (3 mm)	1.4680	0.9190	55.1	53.7	24
7	H_2SO_4	$CH_2=CH-C\equiv C-C(CH_3)(iso\text{-}OC_4H_9)CH_2OH$	90-91 (5 mm)	1.4713	0.9235	55.2	53.7	64
8	H_2SO_4	$CH_2=CH-C\equiv C-C(CH_3)(OC_6H_{13})CH_2OH$	100-101 (3 mm)	1.4703	0.9126	64.3	62.9	65
9	H_2SO_4	$CH_2=CH-C\equiv C-C(CH_3)(OCH_3)CHOH(CH_3)$	75-76 (5 mm)	1.4811	0.9600	45.4	44.3	69-70
10	Na	$CH_2=CH-C\equiv C-C(CH_3)(OH)CH(OCH_3)CH_3$	74-78 (8 mm)	1.4754	0.9543	45.5	44.3	30
11	$(COOH)_2$	$CH_2=CH-C\equiv C-C(CH_3)(OC_3H_7)CHOHCH_3$	96-98 (10 mm)	1.4736	0.9283	55.1	53.6	48
12	H_2SO_4 $(COOH)_2$	$CH_2=CH-C\equiv C-C(CH_3)(iso\text{-}OC_3H_7)CHOHCH_3$	72-73 (3 mm)	1.4709	0.9225	55.2	53.6	58
13	H_2SO_4	$CH_2=CH-C\equiv C-C(CH_3)(OC_4H_9)CHOHCH_3$	95-96 (3 mm)	1.4700	0.9195	59.5	58.3	58

mass. The pure monoethers distill in the absence of air with a little resinification. The resinous products remaining after distilling, exploded upon heating over 140°.

The physical constants and monoether yields are given in the table.

In the presence of acid catalysts, as is shown in the table, the monoether is formed, which possesses a higher boiling temperature, greater specific gravity and index of refraction, as compared with the monoether obtained with alkaline catalyst. On this basis we can assert that with acid catalysts the tertiary monoether is formed in all cases, with the alkaline– the primary (with 2-methyl-epoxy-1,2-hexen-5-yne-3) and the secondary (with 3-methyl-epoxy-2,3-heptene-6-yn-4). A. A. Petrov [2] observed a similar interaction of alcohols with propylene oxide.

It might be assumed that the formation of isomeric monoether mixtures is possible in the first instance To prove the identity of the products obtained, certain synthesized monoethers were carefully fractionated, and , those fractions boiling within an interval of a few degrees possessed the same index of refraction and specific gravity. For example, the methyl ether, obtained from the oxide (I), boiled at 74-77° (4 mm), n_D^{20} 1.4860, d_4^{20} 0.9840 and 77-78° (4 mm), n_D^{20} 1.4859, d_4^{20} 0.9847. The propyl ether, obtained from oxide (II), boiled at 96-98° (10 mm), n_D^{17} 1.4736, d_4^{17} 0.9283 and 98-101° (10 mm), n_D^{17} 1.4736, d_4^{17} 0.9280, while the differences in refractive indices and specific gravity is very considerable between the primary and tertiary monoethers. For example: the methyl ether, obtained from the oxide in the presence of H_2SO_4, has n_D^{20} 1.4860 d_4^{20} 0.9840, and the methyl ether from the same oxide, obtained by the alkaline method, has n_D^{20} 1.4802, d_4^{20} 0.9644.

On the basis of the data obtained, it can be concluded that the rate of formation and the yield of monoethers depends on the oxide structure, on the nature of the catalyst, and on the structure of the reacting alcohol. The disubstituted (2-methyl-epoxy-1,2-hexene-5-yn -3) oxides react more vigorously and give greater yield of condensation products, than the trisubstituted (3-methyl-epoxy-2,3-heptene-6-yn -4).

In the presence of sulfuric acid, the increase in chain length of the reacting alcohol has an almost unnoticeable effect upon the yield of monoether. A chain branching near the hydroxyl group shows noticeable influence. Thus, for example: n-butyl and isobutyl ethers of the oxide (1) are obtained with yields, respectively, of 79 and 64%, and ter-butyl alcohol, in the presence of oxalic acid, does not enter into reaction with this oxide at all.

In the presence of alkaline catalyst, an increase in chain length, or branching near the hydroxyl group of the reacting alcohol, sharply decreases the yield of monoether. This evidently is in full accord with the concept that, with an increase in the chain of the corresponding alcohol, or in its branching, the acidity of the hydrogen atom of the hydroxyl group decreases. Thus, for example, upon interacting the oxide (I) with methyl alcohol in the presence of alkaline catalyst, the reaction product yield reaches 81%, while the yield of condensation product of the given oxide with n-butyl alcohol, under the same conditions, does not exceed 24%.

The reaction of phenol with oxide (I) starts and proceeds with considerable evolution of heat when heated above 60° in the presence of alkaline catalyst. In order to avoid an explosion, the oxide must be added gradually to the phenolate, heated to 60°.

The interaction speed of the alcohols with α-oxides of the vinylacetylene series changes, depending upon the nature of the alkaline catalyst. Thus, for example, with methyl alcohol, in the presence of NaOH, the reaction is complete in 4 hours, and the yield of monoether reaches 68%, while with $Ba(OH)_2$ under the same conditions, there remains some unreacted oxide, and the monoether glycol does not exceed 30%. Upon reaction with acid catalysts, the break in the oxide ring occurs at the carbon attached directly to the triple bond, i.e., the formation of tertiary monoethers occurs. In the presence of alkaline catalyst, the order of linkage is reversed.

EXPERIMENTAL

1. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn- 3 with methyl alcohol in the presence of H_2SO_4. 50 ml of methyl alcohol and 1 drop of H_2SO_4 were placed in a round-bottomed flask with mechanical stirrer and reflux condenser. 15 g of the oxide was gradually added to avoid an increase in temperature over 50° in the reaction mixture. The solution turned dark brown in color. An excess of soda was added to the reaction mixture after 10-15 minutes. The stirring was continued until the coloration had disappeared. The soda was then filtered off, and the excess alcohol removed. The substance obtained was distilled in vacuo (Formula 1 in the table).

0.1167, 0.1031 g substance: 19.0, 16.9 ml CH_4 (11°, 760.6 mm). 0.1059 g substance: 0.2655 g CO_2, 0.0832 g H_2O. Found %: active H 0.697, 0.702; C 68.38; H 8.79. $C_8H_{12}O_2$. Calculated %: active H 0.719; C 68.54; H 8.63.

2. Interaction of 2-methyl-epoxy-1,2-hexen-5-yne- 3 (I) with propyl alcohol in the presence of oxalic acid. To 100 ml of propyl alcohol and 2 g of oxalic acid, was gradually added, with stirring, 39 g of the oxide in such a manner that the temperature of the reaction mixture did not rise above 55°; After addition of oxide, the reaction mixture was heated on a water bath at 80° for 10 minutes. The propyl alcohol excess was partially removed, and the remaining yellowish product washed several times with water, dried with Na_2SO_4 and distilled in vacuo (Formula 3 in the table).

0.1102, 0.1211 g substance: 16.1, 17.7 ml CH_4 (15°, 766.4 mm). 0.0900 g substance: 0.2342 g CO_2. 0.0840 g H_2O. Found %: active H 0.619, 0.621; C 71.13; H 9.24. $C_{10}H_{16}O_2$. Calculated %: active H 0.603; C 71.39; H 8.99.

3. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with n-butyl alcohol in the presence of H_2SO_4. 20 g of the monoether was obtained from 15 g of the oxide, the constants of which are given in the table (Formula 5).

0.1151, 0.1133 g substance: 15.7, 15.4 ml CH_4 (13.5°, 762.6 mm). 0.1082 g substance: 0.2861 g CO_2, 0.0971 g H_2O. Found %: active H 0.579, 0.577; C 72.35; H 10.04. $C_{11}H_{18}O_2$. Calculated %: active H 0.553; C 72.49; H 9.96.

4. Interaction of 2-methyl-epoxy-1,2-hexene-5-yn-3 (I) with sec-hexyl alcohol in the presence of H_2SO_4. 19 g of the monoether was obtained from 15 g of the oxide, its constants being given in the table (Formula 8).

0.1160, 0.1406 g substance: 14.7, 16.9 ml CH_4 (14.5°, 752.2 mm). 0.1102 g substance: 0.2993 g CO_2; 0.1055 g H_2O. Found %: active H 0.508, 0.501; C 74.12; H 10.71. $C_{13}H_{22}O_2$. Calculated %: active H 0.479; C 74.24; H 10.54.

5. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with isobutyl alcohol in the presence of H_2SO_4. 16 g of the monoether was obtained from 15 g of the oxide (Formula 7 in the table).

0.1326, 0.1121 g substance: 17.6, 15.2 ml CH_4 (12°, 757.9 mm). 0.1038 g substance: 0.2749 g CO_2. 0.0939 g H_2O. Found %: active H 0.564, 0.576; C 72.27; H 10.12. $C_{11}H_{18}O_2$. Calculated %: active H 0.553; C 72.49; H 9.96.

6. Interaction of 2-methyl-opoxy-1,2-hexen-5-yne-3 with methyl alcohol in the presence of Na methylate. 1 mole (32 g) of methyl alcohol and 0.4 g of metallic Na was placed in a round-bottomed flask with a reflux condenser. The solution was heated to boiling, and 20 g of oxide then added to it. The heating was then continued for about 4 hours until the oxide odor disappeared. The methyl alcohol excess was then distilled off in vacuo. The remaining viscous mass was washed with water and extracted with ether. The ether solution was dried with Na_2SO_4, the ether removed and the product obtained fractionally distilled in vacuo. 15 g of monoether was isolated (Formula 2 in the table).

0.1379, 0.0918 g substance: 22.9, 15.8 ml CH_4 (14°, 758.3 mm) 0.1121 g substance: 0.2795 g CO_2, 0.0887 g H_2O. Found %: active H 0.700, 0.725; C 68.21; H 8.85. $C_8H_{12}O_2$. Calculated %: active H 0.719; C 68.54; H 8.63.

7. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with methyl alcohol in the presence of NaOH. 1 mole of methyl alcohol, 0.8 g NaOH and 15 g of the oxide were placed in a round-bottomed flask. The reaction mixture was heated for 4 hours. 13 g (68%) of the monoether was isolated with a b.p. 74-75° (5 mm), n_D^{20} 1.4800.

8. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 with isopropyl alcohol in the presence of Na alcoholate. 1 mole of propyl alcohol, 0.4 g of Na and 15 g of the oxide were taken. 14.5 g of the monoether (Formula 4 in the table) was obtained.

0.1280 g substance: 19.2 ml CH_4 (13.5°, 748.3 mm). 0.1254 g substance: 18.9 ml CH_4 (13.5°; 752.2 mm). 0.1058 g substance: 0.2759 g CO_2, 0.0952 g H_2O. Found %: active H 0.625, 0.628; C 71.15; H 9.18. $C_{10}H_{16}O_2$. Calculated %: active H 0.603; C71.39; H 8.99.

9. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with n-butyl alcohol in the presence of Na alcoholate. 20 g of the oxide, 0.5 mole of n-butyl alcohol, 0.2 g of Na were taken. The mixture was heated for 4 hours at 70-80°. 8 g of the monoether (Formula 6 in the table) was obtained.

0.1242, 0.1334 g substance: 16.5, 17.8 ml CH_4 (13°, 752.2 mm). 0.1018 g substance: 0.2700 g CO_2, 0.0994 g H_2O. Found %: active H 0.558, 0.560; C 72.38; H 10.16. $C_{11}H_{18}O_2$. Calculated %: active H 0.553; C 72.49; H 9.96.

10. Interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with methyl alcohol in the presence of $Ba(OH)_2$. 15 g of the oxide, 1 mole of methyl alcohol and 1 g of $Ba(OH)_2$ were taken. The reaction mixture was heated to boiling for 4 hours. 7 g (37%) of monoether with b.p. 74-75° was isolated, n_D^{20} 1.4802, d_4^{20} 0.9642 and a low fraction – non-reacted oxide with n_D^{20} 1.4780.

11. Interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with methyl alcohol in presence of H_2SO_4. 40 ml of methyl alcohol and 5 drops of H_2SO_4 were placed in a round-bottomed flask with mechanical stirrer and reflux condenser. 15 g of the oxide was added gradually in a manner to avoid increase in temperature above that of 45°. 16.5 g of the monoether was isolated (Formula 9 in the table).

0.1091, 0.1339 g substance: 17.1, 21.1 ml CH_4 (16°, 752.5 mm). 0.1182 g substance: 0.3029 g CO_2, 0.1067 g H_2O. Found %: active H 0.649, 0.653; C 69.92; H 9.21. $C_9H_{14}O_2$. Calculated %: active H 0.655; C 70.10; H 9.15.

12. Interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with propyl alcohol in the presence of oxalic acid. A mixture of 50 ml propyl alcohol and 6 g of oxalic acid was heated to boiling, 25 g of the oxide added dropwise over 15 minutes. A noticeable evolution of heat was observed. After addition of the oxide, the reaction mixture was again heated for 10-15 minutes. The alcohol was then partially distilled off; the remaining mass distilled with water, dried with Na_2SO_4 and redistilled in vacuo. 15 g of the monoether was isolated (Formula 11, in the table).

0.1014, 0.1204 g substance: 14.0, 16.3 ml CH_4 (16.5°, 763.5 mm). 0.1004 g substance: 0.2672 g CO_2, 0.0891 g H_2O. Found %: active H 0.579, 0.568; C 72.59; H 9.93, $C_{11}H_{18}O_2$. Calculated %: active H 0.553; C 72.49; H 9.95.

13. Interaction of 3-methyl-epoxy-2,3-hepten-6-yne-4 (II) with isopropyl alcohol in the presence of H_2SO_4. To 50 ml of isopropyl alcohol in the presence of 3 drops H_2SO_4, 15 g of the oxide was gradually added; the reaction mixture temperature rose to 35°. 13 g (Formula 12 in the table) was isolated.

0.1261 g substance: 16.8 ml CH_4 (16°, 752.5 mm). 0.1081 g substance: 0.2865 g CO_2, 0.1060 g H_2O. Found %: active H 0.565, 0.572; C 72.31; H 10.01. $C_{11}H_{18}O_2$. Calculated %: active H 0.553; C 72.49; H 9.95.

14. Interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with isopropyl alcohol in the presence of oxalic acid. A mixture of 50 ml isopropyl alcohol and 5 g of oxalic acid was heated to 70°, and 25 g of the oxide added to it. 10 g of the monoether was obtained with a b.p. of 74-75° (3 mm); n_D^{18} 1.4709; d_4^{18} 0.9229.

15. Interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with n-butyl alcohol in the presence of H_2SO_4. 14 g of the monoether was obtained from 15 g of the oxide (Formula 13 in the table).

0.1564, 0.1217 g substance: 19.4, 15.2 ml CH_4 (15°, 757.1 mm). 0.1121 g substance: 0.3010 g CO_2, 0.1137 g H_2O. Found %: active H 0.521, 0.525; C 73.27; H 10.35. $C_{12}H_{20}O_2$. Calculated %: active H 0.514; C 73.42; H 10.27.

16. Interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with methyl alcohol in the presence of Na methylate. 1 mole (32 g) of methyl alcohol and 0.4 g of Na were placed in a round-bottomed flask with a reflux condenser, and 15 g of the oxide was added to the boiling solution. The reaction mixture was heated at boiling alcohol temperature for 35-40 hours. The alcohol excess was then driven off, and the remaining thick mass was washed with water, extracted with ether, dried with Na_2SO_4 and redistilled in vacuo. 6 g of the monoether was obtained (Formula 10 in the table). 0.111 g sub.: 17.3 ml CH_4(13°, 748.3 mm). Found %: active H 0.650. Calculated %: active H 0.655.

17. Interaction of 2-methyl-epoxy-1,2-hexene-5-yn-3 (I) with phenol in the presence of Na phenolate. 0.3 g of metallic sodium was added to 20 g of phenol at 60°, and 15 g of the oxide was then added gradually; heat evolution was then observed. The addition of oxide was regulated in such a manner as to avoid raising the temp. of the reaction mixture to more than 80-90°. After addition of the oxide, the solution was heated for 30 minutes at 80-90°. The excess phenol was washed out with alkali. The upper layer was removed and the aqueous layer extracted with ether. 18 g of crude viscous product was isolated. The authors were not able to determine its physical constants, because at a temperature over 140° and 1 mm it decomposed.

SUMMARY

1. Upon interaction of 2-methyl-epoxy-1,2-hexen-5-yn-3 (I) with alcohols in the presence of sulfuric acid and oxalic acid, the tertiary monoethers of glycol derivatives of methyl, propyl, n-butyl, isobutyl and hexyl alcohols were isolated.

2. Upon interaction of 3-methyl-epoxy-2,3-hepten-6-yn-4 (II) with alcohols in the presence of the above-indicated reagents, monoethers were obtained – derivatives of methyl, isopropyl, propyl and n-butyl alcohols.

3. Upon interaction of 2-methyl-epoxy-1,2-hexen-5-yne-3 and 3-methyl-epoxy-2,3-heptene-6-yn-4 with alcohols, in the presence of alkaline catalysts (Na alcoholate, NaOH, $Ba(OH)_2$) there separated, respectively, the primary and secondary monoether derivatives of methyl, propyl and n-butyl alcohols.

4. It was determined that the formation of tertiary monoethers of glycols is only realized under the influence of acid catalysts, and in the presence of alkaline catalysts there is formed the primary monoether for 2-methyl-epoxy-1,2-hexen-5-yn-3- and the secondary for 3-methyl- epoxy-2,3-hepten-6-yn-4.

5. It was observed that the rate of formation of the monoethers of glycol in the presence of alkaline catalysts diminishes in proportion to the decrease of hydrogen acidity of the hydroxyl group of the reacting alcohol.

6. The rate of formation of the glycol monoether is lower in the presence of alkaline catalysts, corresponding to a decrease in the solubility of the alkaline catalyst taken in alcohol.

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* See Consultants Bureau translation page 1923.

INVESTIGATION OF OLEFIN OXIDES

VIII. CONDENSATION OF STYRENE OXIDE WITH AMMONIA ON ALUMINUM OXIDE

M. S. Malinovsky and S. N. Baranov

Malinovsky [1,2] and Yurev [3], and also Malinovsky and Baranov [4] have worked out the formation of heterocylic compounds by passing ethylene oxide and ammonia over heated aluminum oxide, or over mixed catalysts ($MgO + Al_2O_3$, $ZnO + Al_2O_3$). But up to the present time all information published has pertained exclusively to ethylene oxide, and formation of heterocylic compounds from other oxides has not been studied by anyone; therefore, our aim was to study the possibility of obtaining heterocylic compound derivatives from substituted ethylene oxide, and namely, from styrene oxide.

The introduction of the phenyl group changes the valence angles in the α-oxide ring, and makes styrene oxide less reactive than ethylene oxide, as was experimentally confirmed in this condensation. At the same time, when most of the heterocylic compounds are formed from ethylene oxide and ammonia at 400-410° over aluminum oxide, styrene oxide under these conditions forms almost no nitrogen-containing products, acetophenone being exclusively obtained; therefore, we decided to increase the temperature to 500°, and along with that, to decrease the volume rate of styrene oxide to 40-42 instead of 70-73, at which the first experiments were conducted.

For the determination of the possible mechanism of formation of heterocylic compounds from styrene oxide, we have also investigated the thermal decomposition of this particular oxide in the absence of ammonia, since we were unable to find directions for its investigation, in the literature.

The thermal decomposition of styrene oxide proceeds with many complications under the above-mentioned conditions. There were found in the condensate not only the isomerization products of the oxide, such as: phenylacetaldehyde and acetophenone, but also aromatic hydrocarbons (benzene, toluene, ethylbenzene, styrene) and also water, dypnone, and small amounts of benzaldehyde and benzoic acid, the yields of which are compiled in the table.

Thermal Decomposition Products of Styrene Oxide (72 g)

Isolated substance	(g)	Isolated substance	(g)
Water	3.0	Phenylacetaldehyde	1.8
Benzene	0.6	Acetophenone	26.0
Toluene	1.8	Dypnone	1.7
Ethylbenzene	3.0	Benzoic acid	0.2
Styrene	7.0		
Benzaldehyde	0.7		

In addition to the liquid products from the thermal decomposition of styrene oxide, there are also formed gases, in which there were found, upon examination in the VTI* [2] apparatus: CO_2 5%; C_nH_{2n} 24%; O_2 2%; CO 8%; H_2 20%; C_nH_{2n+2} 30%. In addition, acetaldehyde and formaldehyde were found qualitatively in the gases.

Upon condensation of styrene oxide with ammonia (temperature 500° and volume rate 40-42) there were found in the condensate, besides the thermal decomposition products of styrene oxide, derivatives of the pyrrole series, and also of pyridine, together with a small amount of ammonium carbonate.

The derivatives of the pyrrole series were indicated only by qualitative reactions (due to their small amounts), while the pyridine bases were not only isolated, but also subjected to analysis. From the pyridine bases, pyridine was substantiated beyond doubt, and also methylphenylpyridine, which could not be successfully separated from one another, as the result of which the structure of the latter remains in question (2-methyl-6-phenylpyridine, 2-methyl-4-phenylpyridine and 2-phenyl-4-methylpyridine could be obtained).

If one considers formaldehyde and acetaldehyde to have been found in the gases, then the pyridine might be formed as the result of their condensation [5].

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EXPERIMENTAL

The thermal decomposition of styrene oxide, and also its condensation with ammonia, were conducted in an apparatus described in the preceding works [1, 2, 4], with the only difference that styrene oxide was added from a buret into the vaporizer, which was heated by an oil bath at 260°, and from here the gaseous styrene oxide passed into the reaction tube.

The styrene oxide was obtained by the method of Fourneau [6] from styrene, using iodine and mercury oxide in ether medium, except that in the last phase of conversion of the iodohydrin into the oxide, alcohol was substituted for ether. To make the point clear, to obtain styrene oxide from iodohydrin in ether medium with the aid of powdered caustic potash, requires, in contrast to the method we describe, not 1-2 days, but 6-7 days at 5-6 times the excess of alkali and stirring of the reaction mass.

The styrene oxide has the following constants: b.p. 190-192° at 747 mm; b.p. 91-94° at 30 mm; d^{21} 1.0120, which coincides with the literature data [6].

1. Thermal Decomposition of Styrene Oxide at 500°. Volume rate of the oxide was 40-42. 72 g was taken for the experiment. The experiment duration was 4 hours. 3 ml of water and 59 ml of oily condensate and 6 liters of gas were obtained.

The oily condensate was washed with 20 ml of 0.1 normal NaOH. The separated alkaline solution, together with water, obtained from the condensation, was carefully steamed off. The residue was dissolved in a small volume of water and acidified with hydrochloric acid; at which time crystals of benzoic acid precipitated, which, after recrystallization, melted at 120-122°, and did not give a depression with benzoic acid.

The oily condensate was dried with calcium chloride and was fractionally distilled from a Favorsky flask. After a few distillations, the following fractions were successfully separated: 1) 75-112° 2.4 g, 2) 130-150°, 10.0 g, 3) 170-180°, 4.0 g, 4) 187-197°, 6.0 g, 5) 200-203°, 15.0 g, 6) 300-340°, 2.7 g.

The first fraction consisted of benzene and toluene, the presence of which was proved by nitration and testing with powdered KOH in petroleum ether [7]. Then was observed a turquoise coloration of the upper part of the alkali and after 1-1.5 minutes an orange-yellow coloration in the lower part, which pointed to the presence of benzene and toluene. 1.5 g of this fraction was oxidized with potassium permanganate, and the non-oxidized liquid was nitrated by a nitration mixture at 100-110°. As a result, dinitrobenzene was obtained, which, after recrystallization from alcohol, had an m.p. of 88° (90° according to the literature data [15]).

From the 2nd fraction was separated, by treatment with bromine water, dibromstyrene, with m.p. 70-71°, which did not give depression upon mixed test (in the literature are cited m.p. 69° [8] and 72-73° [9]).

The residue fraction, after separation of the dibromstyrene, was treated several times with small volumes of sulfuric acid, washed with water and soda, dried with calcium chloride and distilled. In this way, 3 g of ethylbenzene was separated, which had a b.p. of 134-136°; d_4^{20} 0.8650 (according to the literature data [9] the b.p. is 135.8-136.3°; d_4^{20} 0.8664.

From the 3rd fraction benzaldehyde was separated through the bisulfite derivative, and from it the same benzaldehyde by soda solution, which upon standing oxidized easily to benzoic acid with m.p. 121°.

From the 4th fraction the same bisulfite derivative was obtained (in the amount of 3.4 g). After recrystallization from water-alcohol solution, and drying in a vacuum dessicator, the per cent sulfur in it was determined, which corresponded to the bisulfite derivative of phenylacetaldehyde.

0.2314 g substance: 0.2373 g $BaSO_4$. Found %: S 14.11. $C_7H_9O_4SNa$. Calculated %: S 14.28.

The 5th fraction represented almost pure acetophenone, for which was obtained the oxime, with m.p. 59° [11, 15], and from it, by Beckmann rearrangement, acetanilide with m.p. 110-112°, which corresponds exactly with the literature data [15].

The 6th fraction was once more distilled under vacuum (b.p. 220-230° at 20 mm), and from it was obtained the semicarbazone with m.p. 150° after recrystallization from benzene, which corresponds to the melting point of dypnone semicarbazone (151° according to the literature data [13]).

2. Condensation of Styrene Oxide with Ammonia over Alumina. The styrene oxide and ammonia were taken in the molar ratio of 3:1. 72 g of styrene oxide was taken in all; the volume rate was 40-42; the time during which the condensation was conducted was 4 hours and 40 minutes. 53.5 g of condensate and 5200 ml of

gas were obtained in all. Upon fractional distillation, the following fractions were separated: 1) 75-120°, 3.0 g, 2) 120-150°, 6.2 g, 3) 150-180°, 1.7 g , 4) 180-197°, 4.3 g, 5) 197-205°, 24.7 g, 6) 205-260°, 8.0 g, 7) 260-285°, 3.0 g, 8) 285-340°, 1.5 g. 52.4 g of liquid fraction was thus obtained which comprised 72.8% in terms of styrene oxide taken.

In the first fraction were found nitrogen-containing compounds of the pyrrole series (coloring pine splinter treated with vapors of hydrochloric acid). To remove pyrrole compounds in this fraction, gaseous hydrogen chloride was passed through; at which the liquid turned red, and after a given time a precipitate of dark-red resinous substance settled to the bottom of the tube, which was separated from the liquid. The liquid was further treated with a concentrated solution of alkali, and the alkaline solution separated and extracted with ether. The ether extract was mixed with that layer which did not dissolve in alkali, and by fractional precipitation with picric acid, followed by recrystallization from acetone, there was obtained the picrate with m.p. 163°, which did not produce significant depression with the known picrate of pyridine. Thus, among the nitrogen-containing compounds of this fraction is included pyridine.

The subsequent fractions with b.p.'s from 120 to 260° (i.e., the 2nd, 3rd, 4th, 5th and 6th) do not contain nitrogen, and basically represent the same substances which were obtained by thermal decomposition of styrene oxide over alumina at 500° (see above-studied experiment). Thus, the 5th fraction was found to be benzaldehyde , the 6th acetophenone, and so forth.

The fraction with b.p. 260-285° contained nitrogen, and from it was separated a picrate with m.p. 149-152°, which, after 4 recrystallization from acetone, had an m.p. of 158-160°. The determination of nitrogen in the picrate (by the semimicro method):

0.202 g substance: 2.64 ml N_2 (21.5°, 733 mm). Found %: N 14.33. $C_{12}H_{11}N \cdot C_6H_3N_3O_7$.
Calculated %: N 14.07.

From the analysis we concluded that the picrate corresponds to methylphenylpyridine, but we did not succeed in solving the problem of its structure.

From the same fraction after previous treatment with hydrogen chloride (at which time there separated a little of the red-colored tar) there was obtained a platinate, which after recrystallization from hot water, had an m.p. of 198-200° (with decomposition). After drying in a vacuum dessicator over phosphoric anhydride for 24 hours, the platinum percentage in it was determined, for which precipitate an ignition time of 12 hours was required; since the platinate contains a large amount of carbon which is adsorbed by the platinum and burns out with difficulty, this leads to too high a platinum content.

0.3113 g substance; 0.0825 g Pt. Found %. Pt 26.51. $(C_{12}H_{11}NHCl)_2\,PtCl_4$. Calculated %: Pt 26.06.

Analysis of the gas was conducted in the usual way in the VTI apparatus. In the gases were found: CO_2 3.2%; C_nH_{2n} 21%; O_2 0.3%; CO 8.7%; H_2 35%; C_nH_{2n+2} 31%.

Moreover, there was determined acetaldehyde [16] and formaldehyde [16] in the gases before their entrance into the gasometer, proven by qualitative tests.

SUMMARY

1. The thermal decomposition of styrene oxide over aluminum oxide was investigated at 500°, and there were obtained as the basic products of the reaction, besides acetophenone – the aromatic hydrocarbons styrene, ethylbenzene, toluene and benzene, and the aromatic aldehydes benzaldehyde and phenylacetic aldehyde.

2. The condensation of styrene oxide (under the above-indicated conditions) was investigated, in the presence of ammonia. In this case the formation of nitrogen-containing heterocylic compounds was established, among which were demonstrated pyridine, methylphenylpyridine (of undetermined structure) and derivatives of pyrrole.

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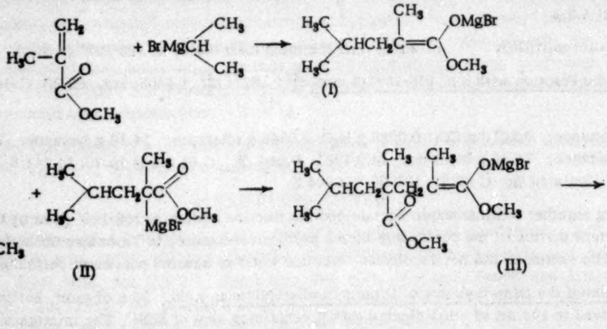
* See Consultants Bureau English translation page 449.

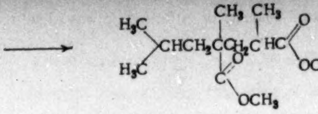
REACTIONS OF THE METHYL ESTER OF METHACRYLIC ACID WITH ORGANO-MAGNESIUM COMPOUNDS

I. REACTION OF METHYLMETHACRYLATE WITH ISOPROPYLMAGNESIUM BROMIDE

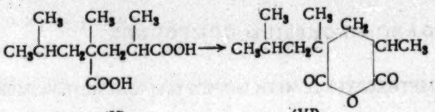
A. I. Lebedeva and E. D. Vainrub

A. E. Favorsky and A. I. Lebedeva investigated the reaction of sulfuric acid with dimethylvinylcarbinol [1] and separated from the mixture obtained at that time several products, among them linalool and geraniol. In the present work we have considered an investigation of the reaction of sulfuric acid and certain other reagents with diisopropylisopropenylcarbinol, where we decided to obtain the latter from the methyl ester of methacrylic acid and isopropylmagnesium bromide. We assumed that the homolog of linalool synthesized in this manner, containing the isopropyl radicals, will possess an entirely different odor and be applied in the perfume industry. However, after carrying out the usual organo-magnesium synthesis, with decomposition of the obtained organo-magnesium complex with water and ice, we obtained mainly a liquid product, with b.p. 108-109° at 4 mm, which contained neither hydroxyl nor carbonyl, and did not react with a water solution of permanganate or with bromine water. A determination of the elementary composition, molecular weight and molecular refraction, has indicated that we obtained the compound corresponding to the formula $C_{13}H_{24}O_4$. Upon saponification of this compound with alcoholic alkali there was obtained a crystalline saturated acid, with an m.p. of 124-125° which, according to the analysis data, corresponded to the formula $C_{11}H_{20}O_4$. The determination of molecular weight, acid equivalent and percentage content of silver in the silver salt of this acid has indicated that the acid obtained by the authors is dibasic, and upon heating easily splits off water and transforms into the anhydride with an m.p. of 73-74°, corresponding to the formula $C_{11}H_{18}O_3$. Upon heating the anhydride with alkali solution it transforms easily into sodium or potassium salt of the acid. Half of the potassium salt was converted into the silver salt and analyzed for the silver content, whereupon the silver content corresponded to the initial acid, the second half of the potassium salt was converted into the original acid. Such ease of anhydride formation is intrinsic only to succinic and glutaric acids, and to their saturated fatty dibasic acid derivatives, which allowed the assumption that a derivative of glutaric acid is formed when conducting the organomagnesium synthesis. K. A. Oglobin [2] obtained a mixture of dimethylisopropenylcarbinol and methyl-sec-butylketone upon reaction of ethylmagnesium bromide with the methyl ester of methacrylic acid under analogous conditions. Upon substituting methyl for the isopropyl, the direction of the reaction might be easily altered. It is known, for example, that it is impossible to obtain the tertiary alcohol upon reaction of isopropylbromide with diisopropylketone in the presence of magnesium [3]. Evidently in our case the linkage of isopropylmagnesium bromide occurs in position 1,4. The transformations indicated can be presented by the following scheme:





(IV)



(V) (VI)

The obtained unsaturated organomagnesium complex (I) isomerizes to the saturated compound (II), and links anew to the second molecule of methyl methacrylate, with the formation of the enol form of the ester of the dibasic acid (III). Upon decomposition of the organomagnesium complex with water, there is formed the dimethyl ester of α,α'-dimethyl-α-isobutylglutaric acid (IV). By saponification of the ester by alkali, there is obtained the free dibasic saturated α,α',-dimethyl-α-isobutyl-glutaric acid (V). The authors have tried to decarboxylate the acid obtained, using the thermal method according to Vogel [4], but instead of the expected hydrocarbon, they have obtained the anhydride of the acid (VI), which distills without decomposition at 287-289°, and melts at 73-74° after recrystallization from petroleum ether (45-75°).

Upon reaction of magnesium phenylbromide with the methyl ester of cinnamic acid (at -10°), Kohler [5] obtained the methyl ester of β,β-diphenylpropionic acid and diphenylpropiophenone. Kohler considered that these products are formed as a result of addition of phenyl-magnesium bromide to the methyl ester of cinnamic acid in position 1,4. At first there evidently occurs addition of one molecule of magnesium phenylbromide, as is quoted in the scheme of A.D. Petrov and P.S. Bataeva [6], with the formation of the methyl ester of β,β-diphenylpropionic acid. However, the reaction may not be terminated at this point only. Petrov and Bataev, investigating the interaction of esters of cinnamic acid with phenylmagnesiumbromide at +20°, have demonstrated that the only reaction product is the saturated 1,1,3,3-tetraphenylpropyl alcohol. The authors have come to the conclusion that termination of the intermediate reaction stage may be conditioned not only by spatial interference, but also by decrease in the temperature of the experiment.

EXPERIMENTAL

Synthesis of the Dimethyl ester of Dimethylisobutylglutaric acid. To 6.5 g of magnesium (in powder form) was added, dropwise, with stirring, 31 g of isopropylbromide in 75 ml of absolute ether. After dissolution of the magnesium, the mixture was stirred for an additional two hours at room temperature, and then cooled on the outside with water and ice, and 13 g of the methylester of methacrylic acid in 25 ml of ether was added dropwise. On the following day the organic magnesium complex was decomposed with water and ice. The ether layer was separated. The remaining residue was decomposed with ice and dilute hydrochloric acid. The solution was treated with ether after the basic salts of magnesium were dissolved. The ether extraction was washed with soda solution, with water, poured into the first ether solution, and the entire ether solution dried with anhydrous magnesium sulfate. The liquid remaining, after distilling off the ether on a water bath, was distilled in vacuo; fractions obtained (at 6 mm); I 94-114°, 2.0 g; II 114-118°, 9.3 g; residue in the flask (tar) 1.5 g.

Fraction II was redistilled, at which time the main mass boiled at 108-109° (4 mm).

Analysis of the Fraction with b.p. 108-109° (4 mm) d_4^{20} 0.9721; n_D^{20} 1.4405; MR_D 66.33. Calculated 65.55.

0.0849 g substance: 0.2013 g CO_2; 0.0788 g H_2O. 0.3346 g substance: 14.10 g benzene: Δt 0.510°. 0.1307 g substance: 14.10 g benzene: Δt 0.198°. Found %: C 64.66; H 10.39; M 241.0, 242.3. $C_{13}H_{24}O_4$. Calculated %: C 63.90; H 9.90. M 244.3.

Upon pouring together semicarbazide acetate and the fraction boiling at 108-109° (4 mm) there was no precipitation. A determination of the percentage active hydrogen (according to Terenteyev-Shcherbakova) gave a negative result. The substance did not decolorize bromine water or aqueous potassium permanganate.

Saponification of the Dimethylester of Dimethylisobutylglutaric Acid. 25 g of ester, boiling at 136-138° (16 mm), was dissolved in 100 ml of ethyl alcohol (96%), containing 15 g of KOH. The mixture was boiled for 5 hours with a reflux. Upon completion of the heating, the mixture was diluted with 3 times the quantity of water, and the alcohol evaporated off. A calculated quantity of sulfuric acid was added to the remaining aqueous solution of the potassium salt of the acid. The precipitated solid acid (16.3 g) was recrystallized first from water (granules with m.p. 116-118°), and then from water-acetone mixture from which the acid was obtained in the form of glittering scales with m.p. 124-125°.

0.1195 g substance: 0.2676 g CO_2; 0.1068 g H_2O. 0.1163 g substance: 0.2586 g CO_2; 0.0952 g H_2O. 0.1465 g substance: 18.2 ml NaOH. 0.1556 g substance: 19.3 ml NaOH (T = 0.002982). 0.2489 g substance: 18.92 g acetic acid: Δt 0.312°. Found %: C 61.10, 60.69; H 9.43, 9.16; equiv. 108.0, 108.1; M 210.1. $C_{11}H_{20}O_4$. Calculated %: C 61.08; H 9.26; equiv. 108.15; M 216.3.

To a solution of the sodium salt of the acid, obtained after determination of the neutralization equivalent, there was added the calculated quantity of silver nitrate. The white precipitate of the silver salt was filtered off, washed with water, alcohol, ether, and dried in a vacuum dessicator over sulfuric acid.

0.2000 g substance: 0.1002 g Ag. 0.3027 g substance: 0.1515 g Ag. Found %: Ag 50.10, 50.05. $C_{11}H_{18}O_4Ag_2$. Calculated %: Ag 50.11.

The analytical data corresponded to α,α'-dimethyl-α-isobutylglutaric acid.

Derivation of the Anhydride of α,α'-Dimethyl-α-isobutylglutaric Acid. 11 g of the acid was placed in a Wurtz flask of 200 ml capacity and the acid slowly heated. After 2 hours the temperature had risen to 250°, at which time there distilled off a small volume of water. All of the liquid was then redistilled at 287-300°. The liquid solidified in the condenser. The solid mass was pressed out on a porous plate, and melted at about 60°. 6.7 g of the solid product was obtained, once more distilled, at which time a fraction was obtained boiling at 287-289°. The product was recrystallized several times from petroleum ether (45-75°), shiny needles with m.p. 73-74° were obtained.

0.1089 g substance; 0.2653 g CO_2; 0.0891 g H_2O. 0.1127 g substance: 0.2753 g CO_2; 0.0922 g H_2O. 0.2872 g substance; 14.23 g benzene: Δt 0.522°. 0.2692 g substance: 16.53 g benzene: Δt 0.415°. Found %: C 66.43; 66.64; H 9.16, 9.16; M 200.3, 203.2. $C_{11}H_{18}O_3$. Calculated %: C 66.65; H 9.15; M 198.2.

Transformation of the Anhydride into the Acid and the Silver Salt. 1.0 g of the anhydride, with m.p. 73-74°, was heated in 50 ml of water with 3 g of KOH until all of the oily drops had disappeared from the surface of the liquid. The cooled solution was divided into two equal parts. To one half was added the calculated quantity of sulfuric acid; whereupon ~ 0.35 g of solid substance precipitated, after recrystallization of which from water, and then from acetone-water mixture, melted at 122-123.5°.

A mixed sample with known acid melted at 122-123.5°.

The second half of the alkaline solution was neutralized with dilute nitric acid and to the solution was added the calculated quantity of silver nitrate. The precipitated silver salt of the acid was filtered off from the solution, washed with water, alcohol, ether, and dried in a vacuum dessicator over sulfuric acid.

0.2018 g substance: 0.1012 g Ag. 0.2212 g substance: 0.1108 g Ag. Found %: Ag: 50.14, 50.07. $C_{11}H_{18}O_4Ag_2$. Calculated %: Ag 50.11.

SUMMARY

1. The reaction of the methyl ester of methacrylic acid proceeds "anomalously" with isopropylmagnesium bromide: instead of the expected diisopropylisopropenylcarbinol, there is obtained instead, the dimethyl ester of α,α'-dimethyl-α-isobutyl-glutaric acid, which can only occur by addition of isopropylmagnesium bromide to methyl methacrylate in the 1,4 position. The dimethyl ester of α,α'-dimethyl-α-isobutyl-glutaric acid converts into α,α'-isobutylglutaric acid upon saponification.

2. Upon slow distillation of α,α'-dimethyl-α-isobutylglutaric acid, its anhydride is formed, which readily reconverts back into the salt of the acid upon heating with alkali.

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[1] A. E. Favorsky and A. I. Lebedeva, Collection of Selected Works of Academician A. E. Favorsky, 507 (1940); J. Gen. Chem. 8, 879 (1938). [2] K.A. Ogloblin, J. Gen. Chem. 18, 2153 (1948). [3] A.D. Petrov and Kh. N. Radshabova, Bull. Acad. Sci. U.S.S.R., Div. Chem. Sci. 1950, 506; D.G. Young and A.N. Roberts, J. Am. Chem. Soc. 66, 1444 (1944). [4] A. Vogel, J. Chem. Soc. 1933, 1028. [5] E. Kohler, Am. Chem. J., 31, 642 (1904). [6] A. D. Petrov and P.S. Bataev, J. Gen. Chem. 20, 2236 (1950).*

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Leningrad State University, A.E. Favorsky Laboratory

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* See Consultants Bureau translation page 2323

[illegible] and the alcohol evaporated [illegible] of the [illegible] salt of the acid. [illegible] crystals with m. p. [illegible] of glistening scales with m. p. [illegible]

[illegible] g substance: [illegible] g CO_2; [illegible] g H_2O. [illegible] g substance: [illegible] ml [illegible] acetic acid [illegible] Found %: [illegible] Calculated %: C 61.08; H 8.28 [illegible]

To a solution of the sodium salt of the [illegible] there was added the calculated quantity of [illegible] washed with water, alcohol, ether, and dried in a vacuum desiccator over sulfuric acid.

[illegible] g substance: [illegible] Found %: [illegible] Calculated %: [illegible]

The analytical data [illegible]

Preparation of the [illegible] was placed in a [illegible] flask of 300 ml capacity [illegible] liquid collected in the receiver [illegible] g of the solid product [illegible] 72.8% were obtained.

[illegible] g substance: [illegible] g substance: [illegible] Found %: [illegible] Calculated %: [illegible]

Transformation of the [illegible] was heated to [illegible] ml of [illegible] base of the liquid. [illegible] quantity of [illegible] then water, and then [illegible]

[illegible]

The second half of the [illegible] added the calculated quantity of [illegible] ether, washed with [illegible]

[illegible] g substance: [illegible] Found %: [illegible] Calculated %: [illegible]

SUMMARY

1. The reaction of the [illegible]

2. [illegible]

LITERATURE CITED

[illegible]

Received March [illegible]

SYNTHESES EMPLOYING ACRYLONITRILE

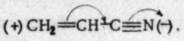
XVI. THE MECHANISM OF THE CYANETHYLATION REACTION

A. P. Terentyev, A. N. Kost and S. M. Gurvich

At the present time the cyanethylation reaction is understood to be the interaction of acrylonitrile with compounds containing a mobile hydrogen atom. By this method, it is possible, under mild conditions, and in good yields, to introduce one or more β-cyanethyl groups into compounds of different types. The breadth of application of this reaction and it great synthetic possibilities have attracted the attention of many synthesis chemists. In a majority of the cases the cyanethylation reaction requires the use of catalysts. Only the hydrogen halides, ammonia, aliphatic amines and strong bases such as hydrazine or piperidine add to acrylonitrile with heat evolution and without the use of a catalyst. For the most part, the use of alkaline reagents is required. In the presence of strong alkali, water, alcohols, phenols, mercaptans, amides, imides, aldehydes, ketones, nitro compounds, certain hydrocarbons, esters, and other compounds cyanethylate. Aromatic amines do not enter into reaction under normal conditions. For cyanethylation of these compounds, prolonged heating, with the addition of acid, must be employed. All of these reaction conditions were experimentally determined.

The authors assume that addition of acryonitrile occurs in many cases by two different schemes [1].

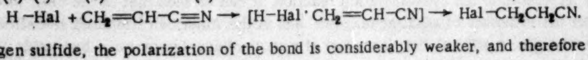
The acrylonitrile molecule possesses a considerable dipole moment ($\epsilon = 3.88$) due to the presence of the nitrile group, i.e., the molecule has a certain tendency to a negative charge on the nitrogen atom, and on the other side, a tendency to a positive charge on the methylene group:



$$(+)\,CH_2{=}CH{-}C{\equiv}N(-).$$

Upon entering into reaction with a substance containing a mobile hydrogen atom, the acrylonitrile evidently forms, at first, an unstable compound at the expense of the methylene group. For realization of such an addition, two situations are theoretically possible: first, linkage to the negatively-charged radical, and secondly – linkage to that atom having a free pair of electrons.

Let us examine the first scheme. In the simplest case, for example in the hydrogen halides, the bond between the hydrogen and the halogen is sharply polarized, the halogen atom being charged negatively, and formation of intermediate compounds occurs easily. Subsequently, there occurs regrouping to the stable state, with the formation of β-haloidopropionitrile:

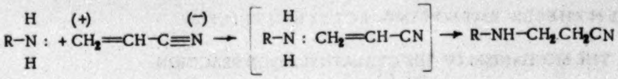


$$\overset{(+)}{H}-\overset{(-)}{Hal}+\overset{(+)}{CH_2}{=}CH{-}C{\equiv}\overset{(-)}{N}\rightarrow[H{-}Hal\cdot CH_2{=}CH{-}CN]\rightarrow Hal{-}CH_2CH_2CN.$$

In hydrogen sulfide, the polarization of the bond is considerably weaker, and therefore it reacts more slowly with the acrylonitrile; upon addition of alkaline agents, however, which polarizes the bond, reaction occurs easily. Alkylmercaptans, for the same reasons react with acrylonitrile only in the presence of alkaline agents, but the arylmercaptans (thiophenols) react comparatively readily without catalysts, where the electron pair placed between the hydrogen and the sulfur atoms is displaced toward the sulfur atom at the expense of the ring influence.

In water and alcohols, polarization of the bond between oxygen and hydrogen atoms is weakly manifested, and therefore reaction occurs only in the presence of alkaline agents. The same phenomenon is observed in compounds capable of cyanethylation with the methylene or methine group. For example, with malonic ester the influence of two carbethoxyl groups imparts a certain tendency to a positive charge on the central carbon atom, but the effect of this charge occurs only under the influence of strong alkaline reagents.

Cyanethylation of compounds containing the amino or imino group is a most interesting case. In primary aliphatic amines (similarly with hydrazine, hydroxylamine or cyclic derivatives of pyrrolidine or piperidine-type) the ability of the hydrogen atom to ionize is not manifested, but the ability for addition is intensely manifested. Here is observed the second scheme of reaction course, namely, addition of acrylonitrile to a free pair of electrons of the nitrogen atom:



$$\overset{H}{\underset{H}{R-N:}} + \overset{(+)}{CH_2}=CH-\overset{(-)}{C\equiv N} \rightarrow \left[\overset{H}{\underset{H}{R-N:}}\ CH_2=CH-CN\right] \rightarrow R-NH-CH_2CH_2CN$$

Reaction proceeds vigorously with heat evolution. The yields of N-substituted β-aminopropionitriles are high. We have systematically studied [2] this type of cyanethylation reaction.

Obviously, the greater the basicity of the amine, the easier should be the course of cyanethylation reaction. Observations of this kind were experimentally carried out [3].

The free pair of electrons of the nitrogen atom is drawn toward the carbon-oxygen double bond, or the carbon-carbon bond in amides, imides, pyrrole and indole. The ability for complex formation is weakened and the nitrogen atom acquires the tendency to a positive charge, and the cyanethylation reaction proceeds only in the presence of alkaline agents, i.e., according to the first scheme.

In aromatic amines, the complex-forming properties of the nitrogen atom are considerably weaker than in the aliphatic and the tendency to hydrogen atom ionization is very negligible. Attempts to carry out the reaction according to the first type, i.e. in the presence of alkaline reagents, were unsuccessful; however, it was empirically found that aromatic amines may be cyanethylated in the presence of acid agents (sulfuric, acetic, phosphoric, hydrochloric acids, acetic anhydride) or copper and nickel salts [4].

These catalysts easily form complex compounds with aromatic amines. Upon heating such a complex (where the nitrogen atom is positively charged) there occurs replacement of the anion by the cyanethyl group, with the establishment of a covalent bond and the displacement of the hydrogen atom. Thus, with the aid of external complexing agents, it is possible to direct the reaction according to the second scheme.

Evidently the cyanethylation in the ring of aromatic compounds that takes place in the presence of anhydrous aluminum chloride, even though slowly, can be regarded in the same light.

Thus, the schemes proposed by the authors practically unify all cases of simple cyanethylation and permit a deliberate choice of reaction conditions.

In both schemes we have assumed that the proton displacement occurs in the second stage of the reaction. The case of initial linkage of the proton, we did not examine, because it is known that in the presence of excess protons their slow addition occurs, not to the methine group, but to the nitrogen atom in the acrylonitrile molecule. Thus, for example, upon sulfuric acid reaction, saponification to acrylic acid occurs [6]. Bruson indicated that cyanethylation of carboxylic acids is not possible [6]. It may be that in this case that reaction of the nitrile group with the protons inhibits cyanethylation. Also omitted is the case of addition of acrylonitrile to free neutral radicals, because this case yields mainly polymerization processes, which is quite amply covered in the contemporary literature.

From a cursory inspection of the cyanethylation reaction, it can be seen that in the most interesting instances it occurs under the influence of alkaline reagents and in the American literature so-called "Triton-B" is frequently mentioned, i.e. a 40% solution (aqueous) of trimethylbenzylammonium hydroxide [6].

The application of organic bases is explained by their good solubility in organic compounds, as a result of which the reaction goes in homogeneous medium, which of course speeds up the process. Wide-spread advertising by American scientists of the catalyst, "Triton B" is partly connected with these advantages of organic bases, but to a greater degree, it seems, is determined by the interests of the firm which manufactures this catalyst.

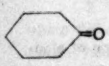
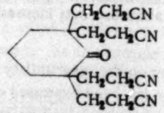
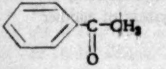
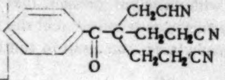
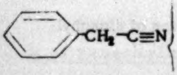
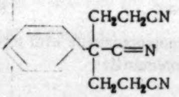
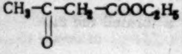
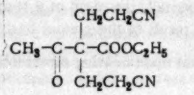
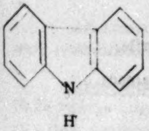
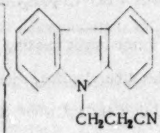
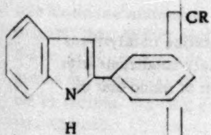
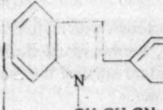
V. M. Rodionov and N. G. Yartseva [7] have shown, in the example of phthalimide cyanethylation, that other quaternary ammonium bases can be utilized with equal success, at which time they proposed a simpler and more easily derived agent, namely an alcoholic solution of ethoxytrimethylphenylammonium hydroxide. According to the work of Rodionov and Yartseva there appeared reports by other authors who utilized methyltriethylammonium hydroxide [8] and butoxytrimethylbenzylammonium hydroxide [9] in the capacity of catalysts.

We have run a series of experiments, applying Rodionov's catalyst for the cyanethylation of various compounds, wherein it was found that the cyanethylation reaction proceeds very vigorously in the presence of this catalyst, and the cyanethylation product yields are not worse, and in a series of cases are better than with the use of "Triton B" [1].

The comparative results are quoted in Table 1.

TABLE 1

Cyanethylation in the presence of Rodionov catalyst

Initial substance	Catalyst	Solvent	Temp.	Reaction product	M. pt.	Yield(in%)	Lit.ref.
	CR	Benzene	25-50		175.5°	95-97	[1]
	TB	"	30-45	"	175	97	[6]
	CR	Benzene	20		129-129.5	65	[1]
	TB	Dioxane	30-40		128-129	57	[6]
	BTBA	ter-C_4H_9OH	20		128-129	64	[9]
	Cr	Benzene	25-30		71.5	90	[1]
	KOH in CH_3OH	ter-C_4H_9OH	10-25		70	94	[6]
 $CH_3-\underset{\displaystyle O}{\overset{\|}{C}}-CH_2-COOC_2H_5$	Cr	Benzene	20	 $CH_3-\underset{\displaystyle O}{\overset{\|}{C}}-\underset{\displaystyle CH_2CH_2CN}{\overset{\displaystyle CH_2CH_2CN}{C}}-COOC_2H_5$	82	83	[1]
	TB	Dioxane	20		82	79	[9]
	BTBA	Dioxane	20		82	80	[9]
	CR	Benzene	0		156.5	89	[1]
	TB	Dioxane	0		155.5	84.5	[10]
	CR	Benzene	60		88-89	82	[1]
	TB	Dioxane	60		88.5-89	80	[11]

Conventional symbols: CR - Rodionov catalyst (alcoholic solution of ethoxytrimethylphenylammonia); TB - "Triton B" (40 % aqueous solution of trimethylbenzylammonium hydroxide); BTBA - butoxytrimethylbenzylammonia.

It should be noted, however, that the use of quaternary ammonium bases are not always advantageous.

In the presence of alkali or alcoholate the reaction proceeds more slowly but is easier to control. It is also inconvenient to use quaternary ammonium bases in those cases where reaction requires heating to more than 60°, because at this temperature decomposition of the catalyst starts.

In examining the reaction mechanics it is necessary to consider the fact that the cyanethylation process occurs reversibly:

$$R{-}H + CH_2{=}CH{-}CN \rightleftarrows R{-}CH_2CH_2CN.$$

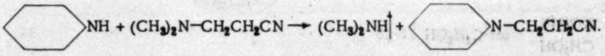
There are directions in the literature to the effect that cyclohexylamine reacts vigorously with acrylonitrile, forming β-cyclohexylaminopropionitrile, but this compound upon distilling (even in vacuo) breaks down very easily into the initial components [12]. Analogous phenomena were observed upon cyanethylation of certain other amines [10,13]. The presence of an equilibrium system in the cyanethylation of amines is also confirmed by the fact that the yields of cyanethylation products increase if either acrylonitrile or amine is taken in excess [2, 10].

There are fragmentary directions on the reversibility of the reaction in the case of cyanethylation of alcohols and phenols [5, 14]. An assumption has been expressed concerning the reversibility of the reaction between chloroform and acrylonitrile [15]. In one of the preceding articles [16] we demonstrated that upon cyanethylation of ammonia there is set up a dynamic equilibrium in all stages of the reaction.

Thus it may be assumed with sufficient grounds, that all cyanethylation reactions are in equilibrium, to a more or less degree. From this assumption it follows that the introduction into the equilibrium system of another compound, capable of being cyanethylated, can result in additional cyanethylation products:

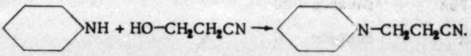
$$R{-}CH_2CH_2CN \xrightleftharpoons[+RH]{-RH} CH_2{=}CH{-}CN \xrightleftharpoons[-R'H]{+R'H} R'{-}CH_2CH_2CN.$$

Actually, upon heating β-dimethylaminopropionitrile with piperidine we have observed separation of dimethylamine with formation of β-piperidylpropionitrile:



Analogously, there was obtained β-dibutylaminopropionitrile from dibutylamine and the same aminonitrile, during which, as would be expected, the yield of β,N-piperidylpropionitrile was found to be higher, than that of β-dibutylaminopropionitrile as a result of the greater basicity of piperidine.

We indicated earlier [17] that upon heating piperidine with ethylenecyanhydrin, there is formed the piperidine cyanethylation product



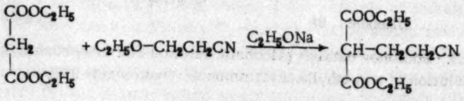
It was found that the same compound is formed upon heating piperidine with β-methoxypropionitrile.

If, instead of piperidine, one takes dibutylamine, then β-dibutylaminopropionitrile is obtained:

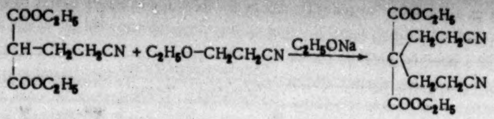
$$(C_4H_9)_2NH + CH_3O{-}CH_2CH_2CN \rightarrow (C_4H_9)_2N{-}CH_2CH_2CN.$$

The authors have carried out all of the reactions described above without catalysts, because in the reaction medium amine was present.

For carrying out the analogous reaction with malonic ester, the introduction of alkaline catalyst was found to be indispensible. And, namely, β-ethoxypropionitrile does not react under ordinary conditions with malonic ester, but in the presence of sodium ethylate the reaction goes with the formation of mono-ana of di-cyanethylation products of malonic ester.



$$\begin{array}{c}COOC_2H_5\\ |\\ CH_2\\ |\\ COOC_2H_5\end{array} + C_2H_5O{-}CH_2CH_2CN \xrightarrow{C_2H_5ONa} \begin{array}{l}COOC_2H_5\\ |\\ CH{-}CH_2CH_2CN\\ |\\ COOC_2H_5\end{array}$$



$$\begin{array}{l} COOC_2H_5 \\ | \\ CH-CH_2CH_2CN \\ | \\ COOC_2H_5 \end{array} + C_2H_5O-CH_2CH_2CN \xrightarrow{C_2H_5ONa} \begin{array}{l} COOC_2H_5 \\ |\;\diagup CH_2CH_2CN \\ C \\ |\;\diagdown CH_2CH_2CN \\ COOC_2H_5 \end{array}$$

Thus, it appeared that the recyanethylation reaction goes slowly and with evolution of considerable heat, at which time splitting of the O—C bond occurs more easily than the N—C bond.

In the literature there are brief directions [5], on the observation that upon heating the product of dicyanethylation of acetamide with acetamide, in the presence of alkaline agents, there occurs recyanethylation:

$$CH_3CON(CH_2CH_2CN)_2 + CH_3CONH_2 \rightarrow 2CH_3CONHCH_2CH_2CN$$

It was of interest to attempt to obtain by this method of monocyanethylated compounds of type $R_2CH-CH_2CH_2CN$ where the cyanethyl group is linked with the carbon atom. As an example acetone was taken, which forms, easily, the tricyanethylated derivative:

$$CH_3COCH_3 \xrightarrow{CH_2{=}CH-CN} CH_3COC(CH_2CH_2CN)_3.$$

Upon heating tricyanethylated acetone with acetone, we presumed to obtain γ-acetobutyronitrile. However, upon combined heating of these substances in the presence of caustic potash for 13 hours at 100° (in a sealed ampoule), or during 6 hours at 150° (in an iron autoclave) we obtained the initial substances and negligible quantity of resin. An attempt to carry out recyanethylation by heating to 100-200° of tri-(β-cyanethyl)-acetone with sodium methylate, or diethylamine, also gave negative results; i.e., it was found that in tricyanethylated acetone, the cyanethyl groups are bound firmly, and under these conditions do not split off.

The results of the authors' experiments on recyanethylation are quoted in Table 2.

EXPERIMENTAL

I. Cyanethylation with Rodionov Catalyst

Rodionov catalyst was prepared according to the method of V. M. Rodionov and N. G. Yartseva [7]. At the time it was noticed that the initial methyl ester of p-tolylsulfoacid should not contain sulfochloride impurity, because otherwise the Rodionov salt turns blue in color, and the activity of the catalyst decreases.

Upon cyanethylation of cyclopentanone and phenylacetonitrile, we examined the influence of sequence of introduction of components into the course of the reaction. If Rodionov catalyst is added to a mixture of acrylonitrile and phenylacetonitrile, then, at low temperatures (0 to 5°) reaction practically fails to go, but if the temperature is raised to 10-15°, a vigorous reaction develops unexpectedly, which acquires the nature of an explosion, even upon adding considerable quantity of neutral solvent (10-15 volumes). The catalyst should therefore be added first and the acrylonitrile then added dropwise.

All compounds obtained by the authors through cyanethylation in the presence of this catalyst (see Table 2) were synthesized by approximately the same methods, and therefore we give a description of a typical experiment.

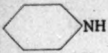
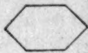
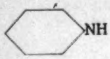
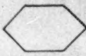
Cyanethylation of Cyclopentanone. S. V. Vitt participated in the carrying out of the experiment. 21 g (0.25 mole) of cyclopentanone, 250 ml of dry benzene and 1 ml of freshly prepared Rodionov catalyst were placed in a flask equipped with stirrer, reflux condenser, thermometer and dropping funnel. With vigorous stirring and external water-cooling, 58 g (1.1 mole) of acrylonitrile was introduced dropwise over a period of 3 hours, the temperature being maintained at 25-30°. If precipitation of crystals was not observed after the addition of 5-8 ml of acrylonitrile, then further addition was stopped, the mixture carefully heated by warm water (not higher than 40°) and 5-6 drops of catalyst added if necessary. After completion of the acrylonitrile addition, the solidified mass was mixed for 2 hours at 40-50°, and left for the night at room temperature. The crystals were then cooled and filtered off by suction. 71-72 g (i.e., 95-97 % of theoretical) of 2,2,5,5-tetra-(β-cyanethyl)-cyclopentanone with m.p. 175.5° was obtained.

Literature data: m.p. 175° (from methylethylketone) [6].

II. Recyanethylation Reactions

1,1,1-Tri-(β-cyanethyl)-acetone was obtained in yield of 73% by reaction of acrylonitrile at 45° with excess acetone in the presence of sodium ethylate. M.p. 151, which corresponds to the literature data [18]. β-Dimethylaminopropionitrile was obtained by a modified method of A.P. Terentyev and A.N Kost [19]. 53 g (1 mole) of acrylonitrile was added in small portions, with vigorous stirring, to 120 g of 50% aqueous solution (1.33 mole) of dimethylamine, after which the mixture was heated under reflux for 5 hours on a water bath. The reaction product was salted out by addition of 50 g of potash, was separated, dried with fused potash, and distilled. 71.5 g of β-dimethylaminopropionitrile was obtained: b.p. 169-171° at 745 mm. Yield 73% of theory.

TABLE 2
Recyanethylation reaction

Cyanethylated compound	Cyanethylating agent	Catalyst	Reaction conditions		Compound obtained	Yield (in %)
			Time(hrs)	Temp.		
 NH	$(CH_3)_2N-CH_2CH_2CN$	Without catalyst	10	160°	 $N-CH_2CH_2CN$	30
$(C_4H_9)_2NH$			40	170	$(C_4H_9)_2N-CH_2CH_2CN$	20
 NH	$CH_3O-CH_2CH_2CN$		15	120	 $N-CH_2CH_2CN$	13
$(C_4H_9)_2NH$			16	180	$(C_4H_9)_2N-CH_2CH_2CN$	15
$COOC_2H_5$ $\vert$ CH_2 $\vert$ $COOC_2H_5$	$C_2H_5O-CH_2CH_2CN$	C_2H_5ONa	10	100	$(C_2H_5OOC)_2CH-CH_2CH_2CN$ $(C_2H_5OOC)_2C(CH_2CH_2CN)_2$	27 10
$CH_3-\overset{\overset{O}{\Vert}}{C}-CH_3$	$CH_3-\overset{\overset{O}{\Vert}}{C}-C(CH_2CH_2CN)_3$	KOH	13	100	Recyanethylation products not found	
$CH_3-\overset{\overset{O}{\Vert}}{C}-CH_3$		KOH	6	150		
$(C_2H_5)_2NH$		Without catalyst	7	60		
CH_3OH		CH_3ONa	7	60		
CH_3OH		KOH	2	200		

β-Methoxy- and β-ethoxypropionitrile were obtained by cyanethylation of the corresponding alcohols in the presence of sodium alcoholate [14].

Cyanethylation of β-dimethylaminopropionitrile. a) A mixture of 9.8 g (0.1 mole) of β-dimethylaminopropionitrile and 15 g (0.17 mole) of piperidine was heated for 10 hours at 160°, during which time continuous evolution of dimethylamine was observed. The piperidine excess was then distilled off, and the residue fractionally distilled in vacuo. Two fractions were obtained: 1st fraction – 6.7 g; b.p. 45-47° at 4 mm; n_D^{20} 1.4920; represented the initial β-dimethylaminopropionitrile. 2nd fraction – 4.1 g; b.p. 77-78° at 3 mm; n_D^{20} 1.4702; d_4^{20} 0.9438; from the constants was identified as β,N-piperidylpropionitrile. The picrate, m.p. 158° (from alcohol) did not give depression with the picrate of β,N-piperidylpropionitrile. Yield of β,N-piperidylpropionitrile was 30% of theory, on the basis of β-dimethylaminopropionitrile.

b) A mixture of 14.7 g (0.15 mole) of β-dimethylaminopropionitrile and 12.9 g (0.1 mole) of dibutylamine was heated for 40 hours at 170° (to the cessation of dimethylamine evolution). After cooling, the reaction mixture was fractionally distilled in vacuo. After distillation of the reaction mixture there was obtained 3.7 g of fraction, b.p. 112-113° at 7 mm; identified as β-dibutylaminopropionitrile; yield 20% of theory; n_D^{20} 1.4450; d_4^{20} 0.8604; MR_D 56.39. $C_{11}H_{22}N_2$. Calculated MR_D 56.76. Picrate m.p. 76° (from alcohol), which corresponded to the literature value [3, 10].

Cyanethylation of β-alkoxypropionitrileamine. a) A mixture of 8.5 g (0.1 mole) of β-methoxypropionitrile and 8.5 g (0.1 mole) of piperidine was heated for 15 hours at 120°. After cooling, the mixture was distilled in vacuo. 1.8 g (13% of theory) β-N-piperidylpropionitrile was obtained. B.p. 76-77° at 3 mm; n_D^{20} 1.4680; d_4^{20} 0.9463. Picrate, m.p. 157° (from alcohol).

b) A mixture of 8.5 g (0.1 mole) of β-methoxypropionitrile and 12.9 g (0.1 mole) of dibutylamine was heated for 16 hours at 180°, and afterwards distilled in vacuo. 2.8 g of β-dibutylaminopropionitrile, i.e. 15% of theory, was obtained. B.p. 98-100° at 3 mm; n_D^{20} 1.4448; d_4^{20} 0.8581. Picrate, m.p. 76° (from alcohol).

c) To a solution of sodium ethylate (2.3 g of sodium in 40 ml of absolute ethyl alcohol) was added 32 g

(0.2 mole) of malonic ester and 9.9 g (0.1 mole) of β-ethoxypropionitrile. The mixture was heated for 10 hours on a water bath, and then 3 times the volume of water was added, acidified with hydrochloric acid, and extracted 4 times with ether. The ether extract was dried with anhydrous sodium sulfate, the ether distilled off, and the residue distilled in vacuo. The products of mono- and di-cyanethylation of malonic ester were obtained. The monocyanethylation product (ethyl ester of α-carbethoxy-γ-cyanbutyric acid) was obtained in quantity amounting to 5.7 g (i.e. 27% of theory). B.p. 140-142° at 5 mm; n_D^{20} 1.4380; d_4^{20} 1.0881; MR_D 51.44; $C_{10}H_{15}O_4N$. Calculated MR_D 51.51. The dicyanethylation product (the dinitrile of γ,γ-dicarbethoxypimelic acid) was obtained in an amount equal to 1.3 g (i.e., 10% of theory). B.p. 193-198° at 5 mm; m.p. 61° (from alcohol).

The constants for both substances corresponded to the literature data [20].

Cyanethylation with tri-(β-cyanethyl)-acetone. a) A mixture of 4.3 g of tri-(β-cyanethyl)-acetone, 18 ml of dry acetone and 0.5 g of solid caustic potash was heated for 13 hours in a sealed flask at 100°. The brown mixture was diluted with double the volume of water and extracted with ether. Upon distillation of the dried ether extract in vacuo, it was not possible to separate the nitrile of γ-acetobutyric acid. The residue after recrystallization from alcohol was found to be the initial tri-(β-cyanethyl)-acetone with m.p. 151°.

An analogous result was obtained upon heating 3 g of tri-(β-cyanethyl)-acetone and 10 ml of acetone in an iron tube for 6 hours at 150° (in the presence of 0.1 g of caustic potash).

b) 0.5 g of sodium was dissolved in 25 ml of absolute methyl alcohol, and then 3 g of tri-(β-cyanethyl)-acetone was added, and the mixture heated for 7 hours under reflux. After cooling, the mixture was neutralized with acetic acid and dried. After distillation of the methyl alcohol and acetone (in vacuo), there remained only the initial tri-(β-cyanethyl)-acetone.

In a second experiment, the vapors of methyl alcohol were conducted through liquid tri-(cyanethyl)-acetone in the presence of caustic potash at 200° for 2 hours. The distillate contained only methyl alcohol. From the reaction flask, in vacuo, up to 200°, nothing distilled over. The residue resinified partially, tri-(β-cyanethyl)-acetone.

c) A mixture of 3 g of tri-(β-cyanethyl)-acetone and 20 ml of diethylamine was heated for 7 hours under reflux. Then the amine was distilled off in vacuo, but the residue was found to be only the initial tri-(cyanethyl)-acetone.

SUMMARY

1. A mechanism was proposed for the cyanethylation reaction, which gives the possibility for explaining and choosing beforehand the catalysts for this reaction.

2. The wide application of ethoxytrimethylbenzylammonium hydroxide (Rodionov catalyst) in the capacity of an alkaline agent for cyanethylation reactions was demonstrated.

3. The reversibility of the cyanethylation reaction was proven in a series of examples. Several cases of recyanethylation were investigated.

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* See Consultants Bureau translation page 1563. ** See Consultants Bureau translation page 1115.

[illegible] a water bath, and after 3 hours the volume of [illegible] was treated [illegible] with [illegible] gases with ether. The ether extract was dried [illegible] in vacuo. The products of [illegible] were [illegible] (i.e. [illegible] of theory). B.p. 140-142° at 5 mm [illegible]. The dicyanoethylated product [illegible] b.p. 192-195° at 4 mm [illegible].

The constants for both substances correspond to [illegible].

Cyanoethylation with [illegible]. [illegible] of 35 ml of [illegible] and 25 g of [illegible] was heated for 12 hours [illegible]. The [illegible] was diluted with a volume of water and [illegible] in vacuo, it was not possible to separate the [illegible].

An analogous result was obtained when heating [illegible] for 6 hours at 140° [illegible].

In 2.5 g of sodium was dissolved in 25 ml of [illegible] was added, and the mixture was heated for 1 hour [illegible]. After cooling, the mixture was [illegible] acetic acid and dried. After distillation of the [illegible] initial [illegible].

In a control experiment, the [illegible] in the presence of caustic potash at [illegible] for 2 hours [illegible] in vacuo [illegible].

c) A mixture of 5 g of [illegible] reflux. Then the [illegible] was distilled off in vacuo, but the residue [illegible] analysis.

CONCLUSIONS

1. A [illegible] was proposed for the [illegible].

2. [illegible]

3. The [illegible] of the [illegible] were investigated.

LITERATURE CITED

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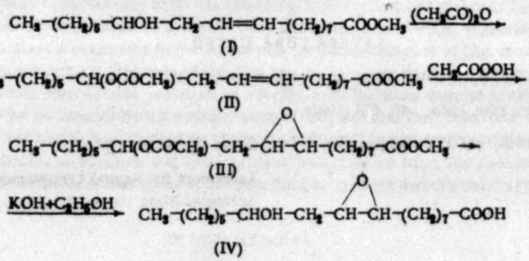
PREPARATION OF RICINOLEIC ACID OXIDE

G. V. Pigulevsky and E. M. Rostomyan

The first studies on preparation of oxides of ricinoleic acid and of its isomer-ricinelaidic acid, were reported by Boeseken and his co-workers [1,2]. These authors obtained ricinoleic acid oxide by oxidation of methyl ricinoleate using benzoyl peroxide with subsequent saponification of the oxidation product.. Ricinoleic acid oxide, separated from salts, was liquid and had $[\alpha]_D^{14}$ −6.6°. It must be noted that only the initial ricinoleic acid appears to have been sufficiently purified. The subsequent steps – preparation of the methyl ester, its oxidation, and separation of the liquid ricinoleic acid oxide – were not accompanied by any purification; consequently there is insufficient assurance of purity in the prepared oxide.

We set ourselves the task, employing results of our earlier studies [3], of synthesizing ricinoleic acid oxide, passing through stages of preparing the acid by individual steps.

The reaction was carried out according to the following scheme:



$$\mathrm{CH_3{-}(CH_2)_5{-}CHOH{-}CH_2{-}CH{=}CH{-}(CH_2)_7{-}COOCH_3} \xrightarrow{\mathrm{(CH_3CO)_2O}}$$

(I)

$$\mathrm{CH_3{-}(CH_2)_5{-}CH(OCOCH_3){-}CH_2{-}CH{=}CH{-}(CH_2)_7{-}COOCH_3} \xrightarrow{\mathrm{CH_3COOOH}}$$

(II)

$$\mathrm{CH_3{-}(CH_2)_5{-}CH(OCOCH_3){-}CH_2{-}\overset{O}{\overbrace{CH{-}CH}}{-}(CH_2)_7{-}COOCH_3} \rightarrow$$

(III)

$$\xrightarrow{\mathrm{KOH+C_2H_5OH}} \mathrm{CH_3{-}(CH_2)_5{-}CHOH{-}CH_2{-}\overset{O}{\overbrace{CH{-}CH}}{-}(CH_2)_7{-}COOH}$$

(IV)

EXPERIMENTAL

Caster oil with an iodine number of 88.3 served as the starting material. The acid separated from caster oil was esterified with methyl alcohol in the presence of HCl (5%). The esterified acid was subjected to fractional distillation under vacuum (0.26 mm). A fraction was separated boiling within the limits of 189-193° with α_D + 5.00°.

According to the literature, b.p. is 245° (10 mm); α_D + 4.68°.

Ricinoleic acid methyl ester (I) was acetylated under usual conditions. The acetylated product was subjected to fractional distillation. The main fraction, boiling between the limits of 181 and 184° (0.14 mm), had the following properties:

d_4^{20} 0.9475; n_D^{20} 1.45697; α_D +20.08°. Iodine No. 76.08 (calculated 71.75).

0.1251 g substance: 0.3286 g CO_2; 0.1249 g H_2O. 0.1242 g substance: 0.2999 g CO_2; 0.1140 g H_2O. 1.1524 g substance: 0.3499 g KOH. 1.1006 g substance: 0.3375 g KOH. Found %: C 71.63. 71.62; H 11.16, 11.16; saponification number 303.2, 306.6 $C_{21}H_{38}O_4$. Calculated %: C 71.19; H 10.73; saponification number 316.4.

The acetylated ester (III) (α_D + 20.68) was oxidized by acetyl peroxide in presence of ether. Acetyl peroxide was taken in some excess (10%). Oxidation was completed in 10 days. The oxide of acetylated methyl ester of ricinoleic acid was fractionally distilled under vacuum (0.12 mm). A fraction with b.p. 187-188° was separated.

α_D + 10.12°; d_4^{20} 0.9819; n_D^{20} 1.45407; MR_D 102.06; calculated 101.93.

0.1238 g substance: 0.3095 g CO_2; 0.1187 g H_2O. 0.1115 g substance; 0.2792 g CO_2; 0.1065 g H_2O. 0.3610 g substance: 0.1060 g KOH; 0.3416 g substance: 0.1012 g KOH. Found %: C 68.18, 68.29; H 10.73, 10.68; saponification number 293.7, 296.3. $C_{21}H_{38}O_5$. Calculated %: C 68.10; H 10.20; saponification number 303.2.

The analytical results show that we prepared the oxide of acetylated methyl ester of ricinoleic acid (III).

The oxide was saponified cold with alcoholic caustic. By addition of the calculated quantity of sulfuric acid to the potassium salt, ricinoleic acid oxide was separated. The latter was extracted using ethyl ether. On evaporation of the ether, the oxide crystallized. M.p. 30-31°. The oxide (IV) was readily soluble in alcohol and poorly soluble in petroleum ether. $[\alpha]_D^{19} -6.68°$.

0.1120 g substance: 0.2816 g CO_2; 0.1135 g H_2O. 0.1168 g substance: 0.2941 g CO_2; 0.1167 g H_2O. Found %: C 68.57, 68.67; H 11.24, 11.18. $C_{18}H_{34}O_4$. Calculated %: C 68.79; H 10.83.

SUMMARY

1. Acetylated ricinoleic acid methyl ester was prepared; it showed high rotation of the polarization plane, $[\alpha]_D +21.2°$.

2. The oxide of acetylated ricinoleic acid methyl ester, prepared for the first time, had the following properties: $[\alpha]_D^{20} +10.31°$; d_4^{20} 0.9819; n_D^{20} 1.45407.

3. Ricinoleic acid oxide, prepared from the oxide of the acetylated methyl ester, was a solid; m.p. 30-31°, $[\alpha]_D^{19} -6.68°$.

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PREPARATION OF $\Delta^{2,3}$-HEXADECENOIC ACID

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Unsaturated hexadecenoic acids, with the double bond in various locations, have remained incompletely studied to the present time. Of the acids of this series, the most investigated appears to be fisitolic acid ($\Delta^{9,10}$) first prepared by Hofstadter [1] from sperm oil. Later it was separated from seal oil by Lyubarsky [2] and by Bauer and Neth [3]; Armstrong and Hilditch [4] prepared it from whale blubber and established its structure. The existence of hypogeic acid [5] is rejected in the studies of a series of investigators [6-9]. Zoomaric acid and the so-called "Bull's acid" are reported to be identical to fisitolic acid (9-hexadecene-1-oic acid) by Toyama [10,11, 12]. In consequence of this study, the confusion which has existed to the present time in the literature on the relationships among the acids of this series, has been resolved. The remaining acids of the series, including the synthetically prepared 7-hexadecene-1-oic and 2-hexadecene-1-oic acids appear incompletely studied and their structure not fully established.

A study of unsaturated hexadecenoic acids has considerable theoretical and practical interest: the same number of carbon atoms occurs in palmitic acid which enters the constitution of many vegetable oils and the fat of marine animals and plays a major role in the fat industry for the manufacture of high-grade hydrogenated edible fats, the nature of which remain incompletely worked out up to the present time. Still it has been shown that hydrogenated fats contain considerable quantities of isoacids, even including those of hexadecenoic acids. The mechanism of formation of isoacids during hydrogenation of fats, and also their behaviour with oxygen, hydrogen, and other reagents has hardly been studied up to the present time. Incompletely studied is also the question of the influence of isoacids on structure and food quality of hydrogenated fats. The literature method reported for preparation of isoacids by splitting out of bromine from brominated derivatives of saturated fatty acids has not been studied sufficiently.

EXPERIMENTAL

The first report on $\Delta^{2,3}$-hexadecenoic acid was given by Ponzio [13]; by the action of alcoholic potassium hydroxide on iodopalmitic acid an unsaturated acid with m.p. 49° was obtained; proof of structure or description of properties were not given.

For the synthesis of $\Delta^{2,3}$-hexadecenoic acid we started with chemically pure palmitic acid [purified by repeated fractional crystallization from benzene (65-70° fraction) and ethyl alcohol] having an m.p. of 62.6-63°. Bromination of the acid was by the method of Hell and Sadowsky [14], previously used by us in the synthesis of $\Delta^{2,3}$-octadecenoic acid [15].

500 g finely divided palmitic acid was charged into a flask (approximately 3 liters capacity), and carefully mixed with 40 g red phosphorous; after this 300 g bromine was cautiously added (over a period of 3 hours) from a dropping funnel. After all the bromine was introduced, when intensity of reaction decreased, the flask's contents were heated on a water bath until hydrogen bromide and excess bromine were removed. A solution of sodium bisulfite was then carefully added until color was removed. α-Brompalmitic acid was extracted using petroleum ether (~1: 6) after 2-3 washes of the dense oily mass with warm water. The ether extract was filtered through paper; the crystals of α-brompalmitic acid which settled after several hours were subsequently recrystallized from the same solvent.

α-Brompalmitic acid purified by this procedure melted at 53-53.5°, in full agreement with the literature value [16]. The yield was 523 g (84% of theoretical).

Analysis for bromine content (by the Stepanov method) [17]:

0.2150 g substance: 0.1198 g AgBr 0.2200 g substance: 0.1233 g AgBr. Found %: Br 23.71, 23.86.
$C_{16}H_{31}O_2Br$. Calculated %: Br 23.85.

α-Brompalmitic acid – crystals of acicular structure and pearly lustre – is readily soluble in organic solvents (petroleum ether, alcohol, acetone, and others).

α-Brompalmitic acid was then treated with an alcoholic solution of potassium hydroxide according to the methods of Ponzio [13] and Le Sueur [18] in order to split out hydrogen bromide and form $\Delta^{2,3}$-hexadecenoic acid. This method was first used by them to prepare $\Delta^{2,3}$-octadecenoic acid from α-bromstearic acid although it was found that the yield of $\Delta^{2,3}$-octadecenoic acid was insignificant. To 100 g α-brompalmitic acid in a porcelain dish was added 240 ml of 30% alcoholic potassium hydroxide (c.p.). The mixture was then heated for 3 hours on a water bath until the alcohol was completely removed. The reaction mass was then diluted with water and made slightly acid with 10% sulfuric acid. The oily material rising to the surface was quickly separated from the liquid and extracted with ethyl ether. The ether extract was dried with calcium chloride, and following separation from the calcium chloride, the ether was evaporated. The residual solid fatty acid, which was a quite brittle mass, was subjected to fractional separation: it was finely crushed in a mortar and dissolved at room temperature in petroleum ether in the ratio of 1:10. The settled material, insoluble in petroleum ether, was separated from the filtrate and set aside (Fraction 1). Petroleum ether in the filtrate was evaporated and the fatty acid residue dissolved in ethyl alcohol in the ratio of 1:5. The alcoholic solution was cooled to minus 5-6°: a small quantity of precipitate (clearly crystalline in structure) formed and was readily removed from the mother liquor by low-temperature filtration (Fraction 2). After the removal of this precipitate, the filtrate was cooled to minus 5-6° again; an additional small quantity of precipitate (crystalline) was obtained and combined with Fraction 2. Following separation of Fraction 2, the filtrate was cooled to minus 10-12°; the copious amorphous precipitate which separated was removed by low-temperature filtration and set aside (Fraction 3). The yields of the fractions are given in the table.

Run No.	Quantity of		Fraction 1		Fraction 2		Fraction 3	
	Brompalmitic acid (in grams)	Solid residue after splitting out bromine (in g)	Grams	%	Grams	%	Grams	%
1	100	70.0	16.0	22.85	3.65	5.15	50.4	72
2	100	76.0	18.0	23.68	5.6	7.37	52.4	68.94
3	100	74.5	17.6	23.62	4.9	6.57	52.0	69.80
4	100	74.9	19.0	25.36	3.5	4.68	52.4	69.95
5	100	74.1	16.0	21.58	2.8	3.78	55.3	74.64

Investigation of Fraction 1. The first residue, separated from the products obtained by treating α-brompalmitic acid with alcoholic caustic, after recrystallization from chloroform (lustrous prisms) melted at 88.5-89° and was not soluble in petroleum ether. It was readily soluble in chloroform and in alcohol with heating. It was evidently α-hydroxypalmitic acid, formed by replacement of bromine by a hydroxyl group (according to the literature [19], its m.p. is 86.5-87°).

0.2406 g substance: 0.6167 g CO_2; 0.2613 g H_2O. 0.1609 g substance: 0.4158 g CO_2; 0.1707 g H_2O. 0.3658 g substance: 13.4 ml 0.1 N KOH 0.4013 g substance: 14.75 ml 0.1 N KOH 0.7900 g substance: 5.03 ml 0.5 N KOH 0.8156 g substance: 5.34 ml 0.5 N KOH Found %: C 69.91, 70.48; H 12.16, 11.88. Acid no. 205.54, 205.81; hydroxyl number by the Normann [20] method, 178.6, 183.6; number of OH groups 1.00, 1.02. $C_{16}H_{32}O_3$. Calculated %: C 70.55; H 11.85. Acid number 206.09; hydroxyl number 178.5.

On the basis of all the above data, we may conclude that the Fraction 1 substance was definitely α-hydroxypalmitic acid.

Investigation of Fraction 2. This fraction separated from the products melted at 49-49.5° and was readily soluble in many organic solvents. It crystallized well from alchol and petroleum ether in the form of shiny rods and evidently appeared to be an unsaturated hexadecenoic acid.

0.1214 g substance: 0.3390 g CO_2; 0.1281 g H_2O. 0.1517 g substance: 0.4240 g CO_2; 0.1600 g H_2O. 0.3476 g substance; 13.65 ml 0.1 N KOH 0.3784 g substance; 14.90 ml 0.1 N KOH Found %: C 76.15, 76.20; H 11.82, 11.81; M 254.65, 254.00. $C_{16}H_{30}O_2$. Calculated %: C 75.52; H 11.89; M 254.24.

The material under consideration had an iodine number, determined by the Hubl method, of 26.3 (theoretical 99.78). It is known from the literature [21] that the closer the double bond is to the carboxylic group, the less is the iodine number.

In order to determine whether it would be possible to approach the theoretical iodine number, experiments were set up with longer holding times than those recommended (by Hubl); the following results were obtained: 26.3 in 24 hours, 46.7 in seven days, 90.0 in 18 days. Evidently, the theoretical iodine number may be attained in this manner for the material under study.

The substance was subsequently subjected to saturation hydrogenation: palmitic acid with m.p. 63° was obtained.

The above data demonstrated indisputably that the material under study in Fraction 2 was an unsaturated acid. In order to fix the location of the double bond, the acid was subjected to oxidative cleavage. For this, 150 ml of a 10% solution of KOH was added to 3 g of the acid. A 5% solution of potassium permanganate was then added step-wise with stirring. The mixture was heated on a water bath and allowed to stand overnight. On the following day, the mixture was decolorized by a solution of sodium bisulfite in the presence of 10% sulfuric acid. The fatty acid which came to the surface, on decolorization and solution of the MnO_2, was extracted by petroleum ether. After two recrystallizations, this material melted at 53.6°, and evidently was myristic acid.

0.2100 g substance: 0.5643 g CO_2; 0.2387 g H_2O. 0.3560 g substance: 15.60 ml 0.1 N KOH 0.2670 g substance: 11.66 ml 0.1 N KOH Found %: C 73.28; H 12.78. Acid no. 245.87, 245.03. $C_{14}H_{28}O_2$. Calculated %: C 73.61; H 12.36. Acid no. 245.42.

The analytical results confirm the presence of myristic acid. No depression was observed in a mixed melting point test with myristic acid.

Consequently, the unsaturated acid subjected by us to oxidative cleavage appears to have been $\Delta^{2,3}$-hexadecenoic acid $CH_3(CH_2)_{12}CH{=}CHCOOH$.

The silver salt of $\Delta^{2,3}$-hexadecenoic acid $C_{16}H_{29}O_2Ag$ was prepared by the action of 0.1 N $AgNO_3$ solution on an alcoholic solution of the sodium salt of the acid under study; it was a crystalline powder of grayish color.

0.1820 g substance: 0.3537 CO_2; 0.1302 g H_2O; 0.0546 g Ag. Found %: C 53.0; H 8.0; Ag 30.0. $C_{16}H_{29}O_2Ag$. Calculated %: C 53.16; H 8.09; Ag 29.87.

The lead salt of $\Delta^{2,3}$-hexadecenoic acid $(C_{16}H_{29}O_2)_2Pb$ was prepared by the action of lead acetate on a warm alcoholic solution of the sodium salt of this acid; it was a white crystalline powder with m.p. 141°.

0.1510 g substance: 0.0635 g $PbSO_4$. Found %: Pb 28.70. $(C_{16}H_{29}O_2)_2Pb$. Calculated %: Pb 29.04.

Ethyl ester of $\Delta^{2,3}$-hexadecenoic acid. 2 g $\Delta^{2,3}$-hexadecenoic acid and 20 ml absolute alcohol were placed in a 50 ml flask fitted with an air condenser; 4 ml concentrated sulfuric acid was then added. The mixture was heated on a water bath for 30 minutes. The ester formed was separated, washed until neutral, and recrystallized from methyl alcohol. $\Delta^{2,3}$-hexadecenoic acid ethyl ester melted at 16°; and was readily soluble in alcohol, acetone, and other solvents.

0.2204 g substance: 0.6149 g CO_2; 0.2380 g H_2O. Found %: C 76.08; H 12.09. $C_{16}H_{29}OOC_2H_5$. Calculated %: C 76.52; H 12.14.

Investigation of Fraction 3. This acid fraction was readily soluble in most organic solvents and melted at 36-38°. This substance, evidently, appeared to be α-ethoxypalmitic acid, formed as a result of replacing bromine by an OC_2H_5 group during reaction of alcoholic caustic on α-brompalmitic acid.

0.2100 g substance; 0.5478 g CO_2; 0.2258 g H_2O. 0.3150 g substance: 0.8317 g CO_2: 0.3358 g H_2O. 0.3293 g substance: 10.95 ml 0.1 N KOH 0.3592 g substance: 11.95 ml 0.1 N KOH Found %: C 71.12, 72.00; H 12.03, 11.94. Acid no. 186.6, 186.7. $C_{18}H_{36}O_3$. Calculated %: C 71.93; H 12.08, Acid no. 186.85.

These data demonstrate that Fraction 3 of the product under study was in fact α-ethoxypalmitic acid $CH_3(CH_2)_{13}CHOC_2H_5COOH$.

Thus, the yield of $\Delta^{2,3}$-hexadecenoic acid was very low, falling within the limits 3.78-7.37%.

In the splitting of hydrogen bromide from α-brompalmitic acid by an alcoholic solution of KOH, what mainly occurs is substitution of bromine by the OH group with formation of α-hydroxypalmitic acid (21.58-

25.36%) or by the OC_2H_5 group with formation of the ethylated acid (68.94-74.64%).

SUMMARY

1. $\Delta^{2,3}$-hexadecenoic acid was prepared in the chemically pure form, its structure was proven and its properties studied.

2. The preparation of unsaturated acids via brom-derivatives of saturated fatty acids is not very effective: for the most part the reaction leads to replacement of bromine by an OH-group with formation of α-hydroxypalmitic acid or by an OC_2H_5-group with formation of α-ethoxypalmitic acid.

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PREPARATION AND STUDY OF PROPERTIES OF $\Delta^{2,3}$-DOCOSENOIC ACID

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Unsaturated fatty acids of the docosenoic type, having the general formula $C_{22}H_{42}O_2$, appear to be incompletely studied. One of the more well known of these acids appears to be erucic acid ($\Delta^{13,14}$-docosenoic acid) which occurs combined in vegetable oils of the mustard family (mustard oil, rapeseed oil, rape oil). Erucic acid was first prepared by Darby [1] and its structure was established by Filety [2]. Cetoleinic acid ($\Delta^{11,12}$-docosenoic acid) is less well known. This acid was first prepared by Toyama [3] who also demonstrated its structure. Several other docosenoic acids have been prepared synthetically, but their structures have not been definitely established. For instance, two isomeric acids – 8-docosene-22-oic and 10-docosene-22-oic – were reported obtained by hydrogenation of erucic acid methyl ester at 200° [4]. The preparation by synthesis of the isoacid 1-docosene-22-oic acid has been reported [5]. Aleksandrov and Zaitsev [6] described an acid prepared by action of an alcoholic solution of potassium hydroxide on iodobehenic acid. The acid they required was prepared by reaction of phosphorous tri-iodide on erucic acid. The "isoerucic" acid they prepared had an m.p. of 54-56°. In the opinion of several investigators [7,8], this acid is entirely similar to erucic acid. Opinions exist [9, 10] that isoerucic acid as prepared by Aleksandrov and Zaitsev is not a pure substance but rather a mixture of acids. The remaining acids of this group have not been studied at all.

EXPERIMENTAL

As raw material for preparation of $\Delta^{2,3}$-docosenoic acid, we used chemically pure behenic acid. Behenic acid with an 81° m.p. was obtained by hydrogenation of chemically pure erucic acid separated from rape oil. α-Brombehenic acid was prepared from behenic acid by methods reported in our previous papers [11, 12].

By the bromination of 250 g behenic acid, 296 g pure α-brombehenic acid was obtained with an m.p. of 70-70.5°, which agrees with the literature value [13]. The yield of α-brombehenic acid was 95-96% of that theoretically possible.

0.2500 g substance: 0.1113 g AgBr (Stepanov). 0.1775 g substance: 0.0783 g AgBr. Found %: Br 18.94, 18.77. $C_{22}H_{43}O_2Br$. Calculated %: Br 19.08.

α-Brombehenic acid was a lustrous fluffy mass of needle-shaped crystals. It was readily soluble in many organic solvents (alcohol, chloroform, acetone, petroleum ether). It crystallized well from petroleum ether. $\Delta^{2,3}$-Docosenoic acid was prepared from α-brombehenic acid.

100 g α-brombehenic acid was placed in a porcelain dish, 240 ml of a 30% alcoholic solution of chemically pure potassium hydroxide was added, and the mixture heated on a vigorously boiling water bath, for 2.5-3 hours, until the alcohol was completely vaporized. The saponified mass was made into a pasty slurry with water and weakly acidified with sulfuric acid (10%). The supernatent fatty material was readily separated from the water layer, washed once with distilled water, and extracted with ethyl ether. The ether solution was dried with calcium chloride and the ether vaporized, yielding 78.6 g of a waxy light yellow solid residue.

In order to study its composition, this latter was fractionally separated using solvents. We assumed that the solid residue was a mixture of ethoxyacids, hydroxyacids, and unsaturated acids, and by analogy with products we had obtained through action of caustic on α-bromstearic acid [11] or an α-brompalmitic acid [12], it was decided first to separate α-hydroxybehenic acid which, according to the literature, melts at 96-97° and is not soluble in petroleum ether. For this purpose the mixture of acids was pulverized as finely as possible and dissolved in petroleum ether in the ratio of 1:10 with gentle heating on a water bath. The insoluble portion of the residue, which we assumed to be α-hydroxybehenic acid, was separated from the filtrate and washed three times with petroleum ether on a Shott funnel. The residue obtained had a 94.5-95° m.p. (Fraction 1). The filtrate from the first separation was cooled to 0°, producing a characteristic crystalline precipitate which was readily separated from the filtrate by low temperature filtration. This second precipitate weighed 3.8 g, m.p. 71-72° (Fraction 2). The filtrate from the second separation was further cooled to minus 3-5°. A copious dense precipitate of finely crystalline material, having an m.p. of 56-57° was obtained (Fraction 3).

The results of three runs in which alcoholic caustic was reacted with α-brombehenic acid and the reaction products fractionally separated are given in the table.

Run No.	Quantity of		Fraction Number					
	α-brombehenic acid used (in grams)	Solid residue resulting from debromination of α-brombehenic acid (g)	1		2		3	
			Grams	%	Grams	%	Grams	%
1	100	79.6	18.6	23.37	3.6	4.6	56.7	71.2
2	100	80.5	12.1	14.70	3.8	4.7	63.2	78.4
3	50	40.0	4.4	11.0	2.5	5.5	32.4	81.0

Assuming that the unsaturated docosenoic acid occurred in Fraction 2, we combined the three portions of this fraction and obtained a material with m.p. 71-72° which was used for further study.

Investigation of Fraction 2. Making the assumption that this fraction consisted of unsaturated $\Delta^{2,3}$-docosenoic acid contaminated with admixtures (hydroxy- and ethoxy-acids), the material was repeatedly fractionally crystallized from petroleum ether and chloroform in order to purify it. This resulted in a pure product with m.p. 68.5-69°.

0.1680 g substance: 0.4799 g CO_2; 0.1852 g H_2O. 0.1468 g substance: 0.4198 g CO_2; 0.1614 g H_2O. Found %: C 77.90, 78.0; H 12.34, 12.31. $C_{22}H_{42}O_2$. Calculated %: C 78.02; H 12.51.

Determination of acid number. 0.2176 g substance: 6.4 ml 0.1 N. KOH 0.2240 g substance: 6.6 ml 0.1 N KOH Found: acid number 165.03, 165.32. $C_{22}H_{42}O_2$. Calculated: acid number 165.72. The iodine number was determined by the Hubl method, and amounted to 18.75 • (theoretical 74.98).

For further study, our product was given a saturation hydrogenation and yielded behenic acid melting at 81°.

The above data demonstrated that we were dealing with an individual unsaturated docosenoic acid.

In order to establish the location of the double bond in the molecular structure of the acid under study, we subjected it to oxidative cleavage using potassium permanganate in alkaline medium. The oxidation procedure is described in our previous paper on the synthesis of $\Delta^{2,3}$-hexadecenoic acid. From the oxidation we obtained a product, having a 75.5° m.p., which after three recrystallizations from ethyl alcohol had an m.p. of 76.2°. This resulting material evidently was arachidic acid.

0.2004 g substance: 0.5631 g CO_2; 0.2300 g H_2O. 0.1800 g substance: 0.5068 g CO_2; 0.2086 g H_2O. Found %: C 76.63, 76.78; H 12.85, 12.97. $C_{20}H_{40}O_2$. Calculated %: C 76.84; H 12.91.

Determination of acid number. 0.1615 g substance: 5.15 ml 0.1 N. KOH 0.1776 g substance: 5.70 ml 0.1 N KOH Found: acid number 178.92, 180.08. $C_{20}H_{40}O_2$. Calculated: acid number 179.65. The iodine number of the resulting product was zero.

Judging from all the above data, we may assert that the product obtained was actually arachidic acid — $C_{20}H_{40}O_2$. Furthermore, a sample mixed with arachidic acid did not melt at a lower temperature.

Consequently, the unsaturated acid appears to be $\Delta^{2,3}$-docosenoic acid with the following structure: $CH_3(CH_2)_{18}CH{=}CHCOOH$.

Preparation of salts of $\Delta^{2,3}$-docosenoic acid. The silver salt of $\Delta^{2,3}$-docosenoic acid was prepared by us by a double decomposition reaction; we heated 0.1 N silver nitrate solution and an alcoholic solution of the potassium salt of the acid under study. The silver salt thus obtained was a gray crystalline powder with a 154-155° m.p.

0.1604 g substance: 0.3461 g CO_2; 0.1342 g H_2O; 0.0387 g Ag. 0.1764 g substance: 0.3834 g CO_2;

• α- and β-unsaturated acids characteristically give reduced iodine numbers.

0.1454 g H_2O; 0.0480 g Ag. Found %: C 58.85, 59.28; H 9.36, 9.23; Ag 24.12, 24.38. $C_{22}H_{41}O_2Ag$. Calculated %: C 59.30; H 9.28; Ag 24.23.

The lead salt of $\Delta^{2,3}$-docosenoic acid was prepared by double decomposition of lead acetate and the sodium salt of the acid under study in an alcoholic medium with heating. Some of the salt prepared was used for a determination of lead content, and the following results were obtained: 0.2004 g substance: 0.0688 g $PbSO_4$. Found %: Pb 23.45. $(C_{22}H_{41}O_2)_2Pb$. Calculated %: Pb 23.49. The lead salt $\Delta^{2,3}$-docosenoic acid was a white crystalline powder melting at 105°.

Preparation of $\Delta^{2,3}$-docosenoic acid ethyl ester. The ethyl ester of $\Delta^{2,3}$-docosenoic acid was prepared by esterification of the acid with ethyl alcohol in presence of sulfuric acid. 2 g pure $\Delta^{2,3}$-docosenoic acid and 20 ml absolute alcohol were placed in a small flask, (50 ml volume); 4 ml concentrated sulfuric acid were added to the mixture. The resulting mixture was heated on a water bath for a period of 30-45 minutes.

The separated ester of $\Delta^{2,3}$-docosenoic acid $CH_3(CH_2)_{18}CH{=}CHCOOC_2H_5$, after removal from the acidic layer, was washed until neutral and crystallized from alcohol. After two recrystallizations it had an m.p. of 40-40.5°.

0.1856 g substance: 0.5362 g CO_2; 0.2060 g H_2O. 0.2042 g substance: 0.5880 g CO_2; 0.2284 g H_2O. Found %: C 78.80, 78.45; H 12.43, 12.52, $C_{22}H_{41}OOC_2H_5$. Calculated %: C 78.62; H 12.66.

Investigation of first and third fractions of product from reaction of alcoholic caustic on α-brombehenic acid. Fraction 1, separated from the reaction products and having an m.p. of 94.5° and insoluble in petroleum ether, appeared evidently to be α-hydroxybehenic acid. It was dissolved in chloroform by warming and crystallized, on cooling, as a fine lustrous prismatic crystalline material. After three recrystallizations from chloroform in the ratio of 1:6, the acid had a 96-97° m.p., which corresponds exactly with the literature value [13].

0.1806 g substance: 0.4904 g CO_2; 0.2023 g H_2O. 0.2709 g substance: 0.7336 g CO_2; 0.2984 g H_2O. Found %: C 74.05, 73.85; H 12.54, 12.33. $C_{22}H_{44}O_3$. Calculated %: C 74.08; H 12.45.

Determination of acid number 0.3118 g substance: 8.8 ml 0.1 N KOH 0.1563 g substance: 4.4 ml 0.1 N. KOH Found: acid number 158.35, 157.96. $C_{22}H_{44}O_3$. Calculated: acid number 157.44.

Determination of hydroxyl number, by Normann method [14]. 0.9640 g substance: 4.9 ml 0.5 N KOH. 0.8676 g substance: 4.4 ml 0.5 N KOH. Found: hydroxyl number 142.54, 139.04. Calculated: hydroxyl number 140.85. Number of hydroxyl groups: 1.01, 0.99.

On the basis of the data obtained we may conclude that the substance studied in Fraction 1 actually is α-hydroxybehenic acid with the structure: $CH_3(CH_2)_{19}CHOHCOOH$.

Fraction 3, separated from the reaction products with an m.p. of 56-57°, after repeated recrystallizations from petroleum ether had a 60-60.5° m.p. This substance, as has been mentioned above, appears to be α-ethoxybehenic acid and has, consequently, the following structure: $CH_3(CH_2)_{19}CH(OC_2H_5)COOH$.

0.3216 g substance: 0.8836 g CO_2; 0.3561 g H_2O. 0.2464 g substance: 0.8114 g CO_2; 0.2794 g H_2O. Found %: C 75.06, 74.82; H 12.40; 12.72. $C_{24}H_{48}O_3$. Calculated %: 74.92; H 12.58.

Determination of acid number. 0.1800 g substance: 4.85 ml 0.1 N. KOH 0.1880 g substance: 4.9 ml 0.1 N. KOH Found: acid number 145.62, 146.23. Calculated: acid number 145.93.

SUMMARY

1. $\Delta^{2,3}$-docosenoic acid has been prepared in the chemically pure state and its structure established. Silver and lead salts as well as the ethyl ester of this acid were prepared.

2. In the action of alcoholic caustic on α-brombehenic acid, some 70-80% of the material reacts to form α-ethoxybehenic acid, approximately 11-23% goes to α-hydroxybehenic acid, and only 4.5-5.5 % forms $\Delta^{2,3}$-docosenoic acid.

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BORON TRIFLUORIDE AS A CATALYST IN ORGANIC CHEMISTRY

VI. REACTION OF O-CHLORPHENOL WITH CYCLOHEXANE

S. V. Zavgorodny

Alkylhalophenols and alkyl halophenyl ethers, according to the literature, have powerful germicidal and insecticidal activity and consequently are of definite interest. They are prepared, usually by halogenation of alkylphenols or alkyl phenyl ethers, and less often by reaction of alcohols or alkyl halides on halophenols. Direct alkylation of halophenols by olefins has hardly been studied.* Continuing our study on alkylation of phenols by olefins, we investigated the reaction of o-chlorphenol and cyclohexene in presence of boron trifluoride ethyl etherate as a catalyst. The reaction was studied at room temperature (16-20°) and at 95-97° using various ratios of reactants. Quantity of catalyst employed was 3-4%. It was established that o-chlorphenol reacts with cyclohexene in presence of $BF_3 \cdot O(C_2H_5)_2$ even at room temperature. Heating the reaction mixture on a boiling water bath significantly increased reactivity, so that the same results were obtained with 2 hours heating on a water bath as had been obtained in 15 days standing of the reaction mixture at room temperature. Increase in length of heating within the limits of 2-8 hours also increased yield of reaction products. However, along with this higher temperature and increased length of reaction time there is a higher degree of polymerization of cyclohexene.

It is noteworthy that for the conditions explored by us (room temperature for 15 days and 95-97° for 8 hours) the sole reaction products appeared to have been etheric compounds. At room temperature, cyclohexyl o-chlorphenyl ether was the only product and almost no polymerization of cyclohexene occurred. As regards phenolic type compounds, their formation under our stated conditions was not observed, at least not in quantities which could be separated by distillation from unreacted o-chlorphenol. Doubling the quantity of cyclohexene reduced reaction velocity at room temperature and reduced the yield of cyclohexyl o-chlorphenyl ether from 48% to 36% for the same length of time. However, at boiling water bath temperature, the ether yield increased from 73% to 79% (in 8 hours).

The extreme stability of cyclohexyl o-chlorphenyl ether toward isomerization also deserves mention. We found that this ether in presence of 25% $BF_3 \cdot O(C_2H_5)_2$ did not isomerize when heated for 8 hours at 120-140°, and in this connection may be fully compared with anisole and phenetole. This appears to be the main reason for the absence of expected phenolic compounds in our products, because they are usually formed by isomerization of alkyl phenyl ethers.

EXPERIMENTAL

We used freshly distilled commercial o-chlorphenol; it was a colorless liquid with a characteristic clinging odor and had b.p. 172-173°; d_{20}^{21} 1.2428. Cyclohexene was prepared by dehydration of cyclohexanol [3]. B.p. 82°; d_{20}^{21} 0.8137. Boron trifluoride ethyl etherate used was freshly distilled at 124-127°.

The reaction was carried out in flasks, having 60 ml volume, into which was weighed o-chlorphenol, catalyst, and finally cyclohexene. On shaking, reactants and catalyst mixed well without significant warming and formed a homogenous almost colorless liquid which rapidly turned light-orange.

On standing the mixture's color became progressively darker, and after 15 days the liquid became dark and opaque although quite limpid. After 2 hours heating on a boiling water bath, the mixture became opaque and after 8 hours heating was converted into a black-colored viscous mass.

After elapse of the specified heating time or the time of standing at room temperature, the reaction

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[*] After this research was concluded, a paper appeared which described alkylation of o-chlorphenol and p-bromphenol with isobutylene and cyclohexene [1,2].

mixture was steam distilled. This vaporized unreacted o-chlorphenol and cyclohexene, lower polymers of cyclohexene and some (very little) of the cyclohexyl o-chlorphenyl ether. The ether product together with polymerized cyclohexene remained in the flask; depending on the test conditions this material was a light-yellow limpid liquid with a lemon odor (runs 1 and 5), a heavy brown oil (run 2), a quite transparent but rather viscous mass (run 3), or a yellow porous semi-solid difficult to separate from water (run 4). For complete removal of phenolic compounds, this material was treated with 10% soda solution, washed with water, dissolved in ether, dried with potash, and vacuum distilled.

Materials taken overhead in the steam distillation were similarly washed with soda solution. This dissolved phenolic compounds. After springing from the alkaline solution by hydrochloric acid, these distilled below 200° and appeared to be unreacted o-chlorphenol. The soda solution insoluble fractions obtained in the first four runs were combined for distillation; corresponding fractions of the last two runs were distilled separately. This material appeared mainly to be unreacted cyclohexene together with a mixture of polymers and ether. All data are given in the table.

In order to identify the etheric compounds prepared, having close boiling point and specific gravity they were recombined and distilled a second time. On distillation of the combined first product fractions, as given in the table, cyclohexyl o-chlorphenyl ether, boiling at 167-170° at 16-17 mm, was separated as the main and practically only product.

d_4^{15} 1.1260; n_D^{15} 1.5489; MR_D 59.47; calculated 58.32. 13.99 mg substance: 35.31 mg CO_2; 9.38 mg H_2O. 8.64 mg substance: 21.83 mg CO_2; 5.87 mg H_2O. 0.1602 g substance: 0.1055 g AgCl. Found %: C 68.88, 68.95; H 7.53, 7.56. Cl 16.29. $C_{12}H_{15}OCl$. Calculated %: C 68.38; H 7.18; Cl 16.83.

Reaction of o-chlorphenol with cyclohexene in presence of borontrifluoride ethyletherate

Run No.	Reaction feed (grams)			Reaction conditions		Ether product - not vaporized in steam distillation					Vaporized in steam distillation	
	o-chlorphenol	cyclohexene	$BF_3 \cdot O(C_2H_5)_2$	Temperature	Time	Total yield before distillation		Obtained after distillation			Insoluble alkali (grams)	Soluble in alkali (g)
						Grams	%	(g)	B.p.mm	d_{20}^{24}		
1	12.20	8.97	0.97	16-20°	15 days	9.67	48.11	8.30	155-57° (15-16)	1.1191	3.95	1.88
2	11.91	7.91	0.83	16-20	24 hrs.	9.75	49.90	5.68	155-80° (17-18)	1.1225	2.80	3.46
				95-97	2 hrs.			3.21	240-75° (15)			
3	11.99	7.81	0.82	95-97	4 hrs.	11.37	56.52				1.80	1.70
4	12.10	8.10	0.93	95-97	8 hrs.	12.48	62.93	5.30	150-68° (12)	1.1276	1.80	2.58
								3.60	215-54° (12)			
5	12.07	16.45	0.91	16-20	15 days	7.20	36.38	4.24	157-65° (16-17)	1.1176	16.20	1.30
6	12.18	14.88	0.91	95-97	8 hrs.	15.77	78.97	–	170-95° (17)	1.1172	9.20	2.00
									245-84° (15)			

The ether was a transparent colorless liquid with a pungent floral odor.

A small amount of material having b.p. 160-166° at 16-17 mm; d_4^{15} 1.1088; n_D^{15} 1.5454; was also separated; ts chlorine content was somewhat low and its carbon and hydrogen contents high, compared with calculated values or cyclohexyl o-chlorphenyl ether.

From steam distillation overhead products which were insoluble in alkali, we separated by a second distilation the dimer of cyclohexene, having b.p. 110-133° at 15-16 mm; d_{20}^{22} 0.9662; n_D^{23} 1.5227; molecular weight 169.4.

Isomerization of cyclohexyl o-chlorphenyl ether in presence of boron trifluoride ethyl etherate. 3.42 g cyclohexyl o-chlorphenyl ether having b.p. 167-170° at 16-17 mm was mixed in a test tube with 0.85 g boron trifluoride ethyl etherate. The tube was sealed and heated for 8 hours at 120-140°. After cooling the tube was opened and the mixture treated with a 5% aqueous sodium hydroxide solution. The cyclohexyl o-chlorphenyl ether taken for the test was quantitatively recovered. The same result was also obtained for the product having a b.p. of 160-166°. Consequently, cyclohexyl o-chlorphenyl ether does not isomerize in the presence of $BF_3 \cdot O(C_2H_5)_2$ under the conditions of our test, and therefore, cyclohexylphenols were not separated.

SUMMARY

1. o-Chlorphenol and cyclohexene react at room temperature in presence of boron trifluoride ethyl etherate to form cyclohexyl o-chlorphenyl ether only.

2. At boiling water bath temperatures polymerization of cyclohexene occurs to a considerable degree together with formation of cyclohexyl o-chlorphenyl ether.

3. Cyclohexyl o-chlorphenyl ether appears to be a compound of considerable stability and does not isomerize in presence of boron trifluoride ethyl etherate when heated at 120-140° for 8 hours.

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DERIVATIVES OF ZINGERONE

V. DERIVATIVES OF RESORCINOL

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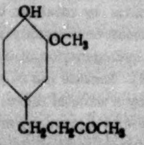
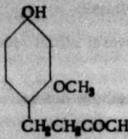
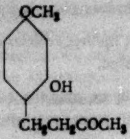
Our earlier papers on synthesis of derivatives of zingerone [1-4] led to a number of relationships between chemical structure and physiological activity for substances having structure similar to 4-hydroxy-3-methoxyphenylethyl methyl ketone (zingerone):



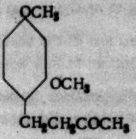
An unanswered question which developed during this work was whether physiological activity of compounds similar to zingerone depended on the relative positions of the hydroxyl and methoxyl groups on the benzene ring. In connection with this we became interested in synthesizing a group of compounds having structural similarity to zingerone, but in which the hydroxyl group would be meta to the methoxyl group and both would be in the 2 and 4 positions with respect to the side chain. The formulas given below show all possible structures for this group of compounds:



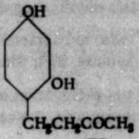
(I)



(II)

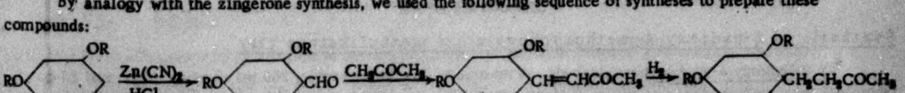


(III)



(IV)

By analogy with the zingerone synthesis, we used the following sequence of syntheses to prepare these compounds:



(R = H or CH_3).

Resorcinol was used as a starting material, and its dimethyl or monomethyl ethers were prepared by methylation with dimethyl sulfate. In preparation of the corresponding aldehydes, we found that 2-methoxy-4-hydroxylbenzaldehyde and 2-hydroxy-4-methoxybenzaldehyde, necessary for synthesis of compounds (I) and (II), were formed simultaneously in almost quantitative yield by action of zinc cyanide on resorcinol monomethyl ether in presence of dry hydrogen chloride. 2,4-Dimethoxybenzaldehyde has been prepared by a similar procedure from resorcinol dimethyl ether, but using aluminum chloride [5]. The aldehydes were condensed with acetone at room temperature in water or in aqueous alcohol in presence of caustic. Hydrogenation of resulting styryl ketones took place smoothly using skeletal nickel catalyst and yielded the corresponding substituted phenylethyl methyl ketones. Using palladium black the reaction is not well-defined and a mixture is obtained containing more completely hydrogenated products.

We experienced considerable difficulty in attempting synthesis of 2,4-dihydroxyphenylethyl methyl ketone (IV). The literature contains indications that benzaldehyde with two ring hydroxyl groups does not condense with acetone [2,6]. Our work confirmed this. It appeared probable to us that 2,4-dihydroxyphenylethyl methyl ketone could be made by demethylation of previously prepared 2-methoxy-4-hydroxyphenylethyl methyl ketone. We performed a series of tests on dimethylation of this compounds under widely different reaction conditions: hydrobromic acid in glacial acetic acid, aluminum chloride in benzene, aluminum chloride in nitrobenzene, heating with aniline hydrochloride, and heating with mixed sulfuric and glacial acetic acids. All these tests resulted in a tarry reaction product from which it was not possible to separate individual substances. Evidently, this may be explained, on the one hand, by the extreme instability of dihydroxyphenylethyl methyl ketone having a hydroxyl group ortho to the side chain, and on the other, by possible enolization of the carbonyl group which could lead to formation of highly condensed cyclic compounds [2] and tars under these relatively severe conditions which are normally employed for saponfication of methyl phenyl ethers. In consequence, we were forced to explore other procedures for synthesis of 2,4-dihydroxyphenylethyl methyl ketone. The problem was whether we could find a substitute for the hydroxyl groups of resorcylaldehyde, which would not be affected during the condensation reaction with acetone carried out in an alkaline medium, but which, nevertheless, could then be readily split off under mild conditions. The benzyl group appeared to us most satisfactory for this purpose. It could be expected that catalytic hydrogenation of the benzyl ether of dihydroxystyryl ketone would lead to splitting off the benzyl groups as toluene at the same time the double bond became saturated. The similar splitting of benzyl groups from nitrogen or sulfur by catalytic hydrogenation is well known. However, cleavage of benzyl ethers under these conditions has been considerably less investigated, although there are references to the use of palladium on carbon for catalytic hydrogenation of several benzyl ethers which were split with formation of toluene and hydroxycompounds [7,8]. Because use of palladium as a catalyst might cause reduction of the carbonyl group, we decided to employ a skeletal nickel catalyst, not used heretofore for cleavage of benzyl ethers. We hydrogenated 4-benzyloxy-2-hydroxystyryl methyl ketone (prepared by condensation of 4-benzyloxy-2-hydroxybenzaldehyde [9] with acetone) in absolute alcohol at room temperature and atmospheric pressure. The quantity of hydrogen necessary for reduction of the double bond was very rapidly absorbed; the balance of the absorption process took place very slowly. The reaction yielded a thick yellowish uncrystallizable oil which could not be distilled even at a 0.2 mm vacuum without substantial decomposition. Consequently, the analyses on the fraction obtained were not wholly satisfactory; however, they were quite adequate to demonstrate that complete removal of benzyl groups by hydrogenation had occurred. Another confirmation of this was that more complete hydrogenation under the same conditions produced a crystalline colorless material, which, according to analyses, was 2,4-dihydroxyphenylethyl methyl carbinol.

In order to characterize most of the phenylethyl methyl ketones as well as several initial aldehydes and styryl ketones, their thiosemicarbazones were prepared.

Of the phenylethyl methyl ketones synthesized by us, only the 4-hydroxy-2-methoxy derivative had a very mild sharp taste; the other ketones did not have this property at all.

We extend thanks to M. N. Shchukinay for guidance in the experimental work.

EXPERIMENTAL

Synthesis of 2-hydroxy-4-methoxyphenylethyl methyl ketone (II)

a) 2-Hydroxy-4-methoxybenzaldehyde. A mixture of 40 g zinc cyanide, 250 ml absolute ether, and 27 g resorcinol monomethyl ether was cooled in water containing ice; a rapid stream of dry hydrogen chloride was passed through the vigorously agitated mixture. During this period, solid zinc cyanide progressively disappeared and the aldimine hydrochloride began to separate as a thick rose-colored oil. Cooling was discontinued and subsequent flow of hydrogen chloride took place at room temperature. The reaction mixture was fully saturated with hydrogen chloride in 3-4 hours. The ether was decanted and the residual viscous mass washed with a small quantity of absolute ether and heated to boiling with 500 ml water. During this operation, the mass hydrolized and the solution became bright-red in color. On cooling the solution, a crystalline material separated which consisted of a mixture of 4-hydroxy-2-methoxybenzaldehyde and 2-hydroxy-4-methoxybenzaldehyde. Following separation of the precipitate by filtration, the filtrate was extracted several times with ether and the residue , recovered after vaporization of ether, was added to the main product portion. The aldehyde mixture was steam distilled. 2-Hydroxy-4-methoxybenzaldehyde was vaporized by the steam and condensed as a colorless oil which crystallized on cooling. Yield 10.2 g; m.p. 39-42° (according to the literature, the m.p. of 2-hydroxy-4-methoxybenzaldehyde is 42° [10].

Thiosemicarbazone – light-yellow crystals (from a mixture of acetone and water), m.p. 214° (with decomposition).

4.872 mg substance: 5.190 mg $BaSO_4$. Found %: S 14.63. $C_9H_{11}O_2N_3S$. Calculated %: S 14.22.

b) 2-Hydroxy-4-methoxystyryl methyl ketone. This was prepared by condensing 2-hydroxy-4-methoxybenzaldehyde with acetone in aqueous caustic. The separated material melted at 125-126° (with decomposition). According to the literature, the m.p. of 2-hydroxy-4-methoxystyryl methyl ketone is 131° [11].

Thiosemicarbazone-grayish yellow crystals, decomposing on standing; m.p. 170-172°.

c) 2-Hydroxy-4-methoxyphenylethyl methyl ketone (II). 2 g skeletal nickel catalyst was added to a solution of 5 g 2-hydroxy-4-methoxystyryl methyl ketone in 100 ml absolute alcohol, and the mixture hydrogenated at room temperature and atmospheric pressure. After removal of catalyst and vaporization of solvent, the residue was vacuum distilled; during distillation the material decomposed and became violet-colored. A fraction boiling at 142-145° at 0.2 mm was collected; it was a colorless viscous liquid, readily soluble in alcohol and ether but insoluble in water.

4.870 mg substance: 12.077 mg CO_2; 3.139 mg H_2O. Found %: C 67.63; H 7.21. $C_{11}H_{14}O_3$. Calculated %: C 68.04; H 7.21.

Thiosemicarbazone – colorless crystals shaped like elongated prisms; m.p. 135-137°.

0.1319 g substance: 0.1125 g $BaSO_4$. Found %: S 11.78. $C_{12}H_{17}O_2N_3S$. Calculated %: S 11.98.

Synthesis of 2-methoxy-4-hydroxyphenylethyl methyl ketone (I)

a) 2-Methoxy-4-hydroxybenzaldehyde. 2-methoxy-4-hydroxybenzaldehyde was formed simultaneously with 2-hydroxy-4-methoxybenzaldehyde by action of zinc cyanide on resorcinol monomethyl ether in presence of hydrogen chloride (see above). The residue after steam distillation of 2-hydroxy-4-methoxybenzaldehyde was boiled with carbon; on cooling, 17 g 2-methoxy-4-hydroxybenzaldehyde (from 27 g resorcinol monomethyl ether) came out of solution as a crystalline lightly rose-colored material, m.p. 156-158° (according to the literature, m.p. of 2-methoxy-4-hydroxybenzaldehyde is 153° [10]).

Thiosemicarbazone – light yellow crystals (from aqueous alcohol), m.p. 196.5° (with decomposition).

5.471 mg substance: 5.546 mg $BaSO_4$. Found %: S 13.92. $C_9H_{11}O_2N_3S$. Calculated %: S 14.22.

b) 2-Methoxy-4-hydroxystyryl methyl ketone. To a solution of 4 g 2-methoxy-4-hydroxybenzaldehyde in a mixture of 48 ml 2.5% NaOH solution and 8 ml acetone, 12 ml 10% NaOH solution was added during the course of an hour followed by 120 ml water. The transparent dark red solution was allowed to stand at room temperature for two days and then diluted to 400 ml with water and cautiously acidified with hydrochloric acid until weakly acid to Congo Red. The bright-yellow crystals which separated were removed by filtration, washed with water, and dried in a vacuum desicator. After recrystallization from aqueous alcohol using carbon, the substance had m.p. 165-166.5°. Yield 2.5 g.

4.248 mg substance: 10.763 mg CO_2; 2.411 mg H_2O. Found %: C 69.10; H 6.35. $C_{11}H_{12}O_3$. Calculated %: C 68.75; H 6.02.

Thiosemicarbazone – thick hexahedral plates (from 96% alcohol), m.p. 201-202° (with decomposition).

4.425 mg substance: 3.950 mg $BaSO_4$. Found %: S 12.26. $C_{12}H_{15}O_2N_3S$. Calculated %: S 12.07.

c) 2-Methoxy-4-hydroxyphenylethyl methyl ketone (I). 3 g skeletal nickel catalyst was added to a solution of 7.45 g 2-methoxy-4-hydroxystyryl methyl ketone in 75 ml 96% alcohol and the mixture hydrogenated at room temperature and atmospheric pressure. Absorption of hydrogen was complete in 20 minutes. After removal of catalyst, the solvent was vaporized by vacuum; and the residue crystallized. Material recrystallized from hot water using carbon had m.p. 116-118°; colorless prisms, readily soluble in alcohol and acetone, difficultly soluble in water. Yield 5.8 g.

3.301 mg substance: 8.202 mg CO_2; 2.191 mg H_2O. Found %: C 67.76; H 7.42. $C_{11}H_{14}O_3$. Calculated %: C 68.04; H 7.21.

Thiosemicarbazone – colorless plates (from aqueous alcohol), m.p. 176-178°.

4.559 mg substance: 4.060 mg $BaSO_4$. Found %: S 12.23. $C_{12}H_{17}O_2N_3S$. Calculated %: S 11.98.

Synthesis of 2,4-dimethoxyphenylethyl methyl ketone (III)

a) 2,4-Dimethoxybenzaldehyde was prepared by action of zinc cyanide on a benzene solution of resorcinol dimethyl ether in presence of hydrogen chloride and aluminum chloride [5]. M.p. 67-70° (according to the literature, m.p. of 2,4-dimethoxybenzaldehyde is 68-71° [5]).

Thiosemicarbazone – light yellow crystals (from aqueous alcohol), m.p. 194-195° (with decomposition).

5.178 mg substance: 5.035 mg $BaSO_4$. Found %: S 13.35. $C_{10}H_{13}O_2N_3S$. Calculated %: S 13.38.

b) 2,4-Dimethoxystyryl methyl ketone. 9.2 ml acetone and 14 ml 10% NaOH solution were added to a a solution of 4 g 2,4-dimethoxybenzaldehyde in 25 ml 96% alcohol. The mixture was allowed to stand for two days at room temperature. The liquid was then poured into 500 ml water; the thick dark yellow oil which separated was extracted using benzene. After drying the benzene solution and evaporation of solvent under vacuum, the residue was distilled at 2 mm; during distillation the material became considerably resinous and decomposed. A fraction (2.6 g) was separated having b.p. 185-190°, it was a thick, yellow oil.

Thiosemicarbazone of 2,4-dimethoxystyryl methyl ketone – spindle-shaped bright yellow crystals (from aqueous alcohol), m.p. 168-170°.

4.871 mg substance: 4.080 mg $BaSO_4$. Found %: S 11.50. $C_{13}H_{17}O_2N_3S$. Calculated %: S 11.47.

c) 2,4-Dimethoxyphenylethyl methyl ketone (III). A solution of 2.4 g 2,4-dimethoxystyryl methyl ketone in 50 ml absolute alcohol was hydrogenated in presence of skeletal nickel catalyst (1 g) at room temperature and atmospheric pressure. When hydrogenation was completed, the catalyst was removed by filtration, the solvent removed by distillation, and the residue – an uncrystallizable oily liquid – vacuum distilled. A fraction with b.p. 142-145° at 2 mm was obtained – colorless liquid, readily soluble in alcohol and acetone but insoluble in water.

3.218 mg substance: 8.164 mg CO_2; 2.196 mg H_2O. Found %: C 69.19; H 7.64. $C_{12}H_{16}O_3$. Calculated %: C 69.23; H 7.69.

Synthesis of 2,4-dihydroxyphenylethyl methyl ketone (IV)

a) β-Resorcyl aldehyde was prepared by action of zinc cyanide on an ether solution of resorcinol in presence of hydrogen chloride [12]. M.p. 136-137° (according to the literature, m.p. of β-resorcyl aldehyde is 135-136° [12]).

Thiosemicarbazone – fine white needles (from 50% alcohol), m.p. 222.5° (with decomposition).

3.559 mg substance: 3.988 mg $BaSO_4$. Found %: S 15.38. $C_8H_9O_2N_3S$. Calculated %: S 15.16.

b) 4-Benzyloxy-2-hydroxybenzaldehyde. This was prepared by benzylation of 8 g resorcyl aldehyde using benzyl chloride in absolute alcohol in the presence of sodium alcoholate [9]. 2 g of a substance was obtained, m.p. 77-80° (according to the literature, m.p. of 4-benzyloxy-2-hydroxybenzaldehyde is 77-80° [9]).

Thiosemicarbazone – glistening thin plates (from alcohol), m.p. 210-211°.

6.865 mg substance: 0.846 ml N_2 (23°, 739.0 mm). Found %: N 13.81. $C_{15}H_{15}O_2N_3S$. Calculated %: N 13.95.

c) 4-Benzyloxy-2-hydroxystyryl methyl ketone. 4 ml acetone and 24 ml 2.5% NaOH solution were added to 3 g 4-benzyloxy-2-hydroxybenzaldehyde. A voluminous white precipitate of the sodium aldehyde derivative formed at once. To the resulting mass, 12 ml 10% NaOH solution was added, during the course of an hour, with stirring, followed by 50 ml water. The mixture was shaken for 60 hours, during which most of the mass slowly went into solution and the liquid developed an intense orange-red color. The remaining undissolved precipitate was removed by filtration, and the filtrate cautiously acidified with 2% hydrochloric acid solution until weakly acid to Congo red. The yellowish precipitate of styryl ketone was separated by filtration, dried, and washed twice with boiling petroleum ether to remove admixed initial aldehyde. After repeated recrystallization from 70% alcohol the material had m.p. 167°; lightly rose-tinted, elongated prisms readily soluble in acetone and boiling alcohol, insoluble in water. Yield 1.3 g.

3.101 mg substance: 8.602 mg CO_2; 1.593 mg H_2O. Found %: C 75.65; H 5.75. $C_{17}H_{16}O_3$. Calculated %: C 76.12; H 5.97.

From the sodium aldehyde derivative which did not enter the reaction, 1.6 g 4-benzyloxy-2-hydroxybenzaldehyde was recovered.

d) Catalytic hydrogenation of 4-benzyloxy-2-hydroxystyryl methyl ketone. A solution of 1 g 4-benzyloxy-2-hydroxystyryl methyl ketone in 50 ml absolute alcohol was hydrogenated at room temperature and atmospheric pressure in presence of 1 g skeletal nickel catalyst. According to calculation, 186 ml H_2 (17°, 734 mm) is necessary for saturation of the double bond and removal of the benzyl group. The first 90 ml was absorbed very quickly, then hydrogenation became much slower, and finally absorption of hydrogen took place very slowly. After absorption of 200 ml hydrogen, the hydrogenation was stopped, catalyst filtered, solvent removed in vacuum, and the residue – a thick yellowish liquid – vacuum distilled. During distillation the material became considerably resinous and decomposed, and it was not possible to achieve its complete purification. A fraction was separated with b.p. 175° at 0.3 mm which was a thick non-crystalline yellow mass. The analytical data show that together with reduction of the double bonds, the benzyl group was almost completely removed while the carbonyl group remained unattacked.

5.969 mg substance: 14.969 mg CO_2; 3.757 mg H_2O. 4.227 mg substance: 1.06 ml CH_4 (17°, 737 mm). Found %: C 68.39; H 7.04; OH 17.51. $C_{10}H_{12}O_3$. Calculated %: C 66.66; H 6.66; OH 18.88.

Saturation hydrogenation under the same conditions gave a colorless crystalline material, m.p. 114-116°.

3.323 mg substance: 8.028 mg CO_2; 2.313 mg H_2O. Found %: C 65.89; H 7.77; $C_{10}H_{14}O_3$. Calculated %: C 65.70; H 7.69.

SUMMARY

1. We synthesized several zingerone-type compounds; they appear to be resorcinol derivatives having the hydroxyl and methoxyl groups in different positions of the benzene ring.

2. We found that all these compounds had practically no sharp taste.

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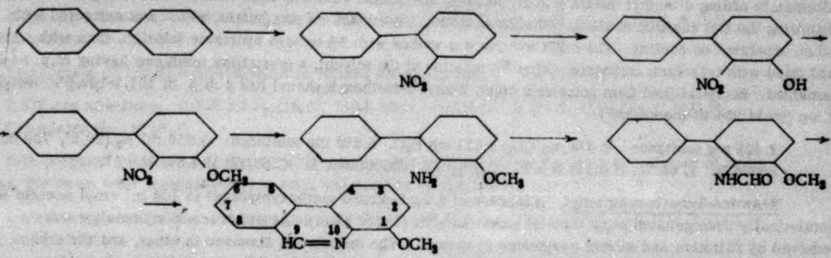
SYNTHESIS OF 1-METHOXYPHENANTHRIDINE

A. Ya. Berlin and T. P. Sicheva

Monomethoxy substituted phenanthridines have not been reported in the literature until this time. While engaging in study of a group of derivatives of phenanthridine, we found it necessary to synthesize phenanthridine with a methoxyl group in the 1-position.

We planned to prepare this material by the following scheme:



Biphenyl, the starting material for this synthesis, was prepared via phenyl magnesium bromide [1] with 85-95% yield.

We introduced the hydroxyl group into o-nitrobiphenyl by action of anhydrous potassium hydroxide in benzene solution [3]. It should be mentioned that this reaction was accompanied by considerable resin formation, which is associated, evidently, with the oxidation process, and it was not possible to obtain a satisfactory yield. By carrying out a series of experiments at different conditions, it was determined that the best yield of 2-nitro-3-hydroxybiphenyl (approximately 30% of theoretical) was obtained by performing the reaction at 90-95° over a 6-7 hour period; under these conditions a portion of the initial 2-nitrobiphenyl may be recovered.

We methylated 2-nitro-3-hydroxybiphenyl using dimethyl sulfate in caustic medium, yield was 90-96% of theoretical. The 2-nitro-3-methoxybiphenyl obtained was catalytically hydrogenated at atmospheric pressure and room temperature using skeletal nickel catalyst. Hydrogenation was performed both in alcohol and in ethyl acetate solution. In the latter, nitro group reduction took place considerably more rapidly and with quantitative yield of 2-amino-3-methoxybiphenyl.

By heating 2-amino-3-methoxybiphenyl with formic acid we prepared 2-formylamino-3-methoxybiphenyl, which was then subjected to ring closure using zinc chloride at 280-300° [4]. Considerable tar-formation occurred during ring-closure; we were able to separate only a very small amount of the base which was then converted to the picrate. In recrystallization of the picrate, two materials with different melting points and different crystalline forms were separated. Analytical data showed that they were the picrates of 1-hydroxy- and 1-methoxyphenanthridine; from this it follows that the process of ring closure using zinc chloride leads to partial saponification of the methoxyl group.

The very small quantity of base separated from these picrates was purified by sublimation. Two materials were obtained thereby, which, according to the analytical data, were 1-hydroxyphenanthridine and 1-methoxyphenanthridine.

EXPERIMENTAL

2-Nitro-3-hydroxybiphenyl. A mixture of 3 g 2-nitrobiphenyl, 30 g finely subdivided potassium hydroxide, and 30 ml absolute benzene was agitated at 90-95° for 7 hours. After cooling the dark red reaction mass was poured into water, the benzene layer separated, and the aqueous layer extracted several times with benzene. About 0.5 g of the initial 2-nitrobiphenyl were recovered from the benzene solution after removal of solvent.

The water layer was acidified with concentrated hydrochloric acid until acid to Congo red, and the dark oily precipitate which was formed extracted with ether. After removal of the ether, the residual dark tarry mass was repeatedly extracted with a saturated aqueous solution of sodium bicarbonate. This solution was acidified with hydrochloric acid; the dark crystalline precipitate which formed was removed by filtration, and dissolved in a small amount of ethyl alcohol; the resulting solution was diluted with three times its volume of water. Most of the tarry contaminants remained in solution in this step, and the precipitate which separated was almost pure 2-nitro-3-hydroxybiphenyl in the form of bright yellow crystals. Weight 1 g. After recrystallization from petroleum ether the material had m.p. 82-84° (according to the literature the m.p. of 2-nitro-3-hydroxybiphenyl is 81-82° [3]).

2-Nitro-3-methoxybiphenyl. To a hot bright red solution of 2.3 g 2-nitro-3-hydroxybiphenyl in 7 ml of 7% sodium hydroxide solution, was added 1.2 ml freshly distilled dimethyl sulfate and the mixture heated with agitation for 15 minutes; 17% sodium hydroxide solution was then added until alkaline. We continued, alternately adding dimethyl sulfate (0.5 ml portions) and caustic solution, until a red color no longer developed following the last addition of alkali (alkaline to litmus). A crystalline precipitate, which was extracted with ether, separated on cooling. The ether solution was washed with 2% sodium hydroxide solution, then with water, and dried with potassium carbonate. After evaporation of the solvent, a crystalline substance having m.p. 84-92° remained. Recrystallized from petroleum ether, 2-nitro-3-methoxybiphenyl had a m.p. of 101.5-102.5°. Weight 2.3 g (yield 95% of theoretical).

2.429 mg substance: 6.074 mg CO_2; 1.111 mg H_2O. 6.598 mg substance: 0.350 ml N_2 (20.5°, 729 mm). Found %: C 68.20; H 5.12; N 5.92. $C_{13}H_{11}O_3N$. Calculated %: C 68.12; H 4.80; N 6.11.

2-Amino-3-methoxybiphenyl. A solution of 3.9 g 2-nitro-3-methoxybiphenyl in 100 ml ethyl acetate was catalytically hydrogenated using skeletal nickel catalyst (5 g of paste). At end of reaction, catalyst was removed by filtration and solvent evaporated in vacuum. The residue was dissolved in ether, and the ether solution extracted with 2% hydrochloric acid solution. A dark-colored crystalline material was formed on evaporation of the acid solution. The weight of 2-amino-3-methoxybiphenyl hydrochloride was 4 g. The hydrochloride was dissolved in an excess of hydrochloric acid and the solution heated with carbon. After removal of carbon and addition of sodium hydroxide solution until alkaline, a white finely-crystalline precipitate was separated. On recrystallization from aqueous alcohol, 2-amino-3-methoxybiphenyl had m.p. 59-60.5°.

3.192 mg substance: 9.195 mg CO_2; 1.860 mg H_2O. 6.757 mg substance: 0.430 ml N_2 (19.5°, 725.0 mm). Found %: C 78.56; H 6.52; N 7.09. $C_{13}H_{13}ON$. Calculated %: C 78.39; H 6.53; N 7.03.

The picrate of 2-amino-3-methoxybiphenyl was prepared by addition of a saturated solution of picric acid in absolute ether to a solution of the amine in the same solvent. After recrystallization from water the substance had an m.p. of 153.5°.

3.428 mg substance: 0.395 ml N_2 (19.5°, 737.5 mm). Found %: N 13.04. $C_{13}H_{13}ON \cdot C_6H_3O_7N_3$. Calculated %: N 13.08.

2-Formylamino-3-methoxybiphenyl. A mixture of 2.5 g 2-amino-3-methoxybiphenyl and 5 ml freshly distilled formic acid was heated on an oil bath for 2 hours at 140°. Formic acid was then removed under vacuum; the residue was then ground with petroleum ether, whereupon the material crystallized. Crystals were removed by filtration, washed with petroleum ether, and dried. Weight 2.6 g. In order to remove unreacted amine, the material was dissolved in ether, and the ether solution extracted with 2% hydrochloric acid. After washing with water and removal of solvent, the residue was recrystallized several times from ether. Pure 2-formylamino-3-methoxybiphenyl had m.p. 113-114°.

7.660 mg substance: 3.38 ml 0.01 N H_2SO_4 (Kjeldahl). Found %: N 6.18. $C_{14}H_{13}NO_2$. Calculated %: N 6.16.

1-Methoxyphenanthridine. 2.4 g 2-formylamino-3-methoxybiphenyl and 6 g fused zinc chloride were placed in a round-bottom flask fitted with a thermometer reaching to the bottom and an air condenser. The mixture was heated on a Babo funnel for 6 hours at 240-290°. At the end of the reaction, the mass had turned very dark. The reaction mixture was treated with hot water, and the resulting greenish-brown precipitate was separated by filtration and treated with a 10% hydrochloric acid solution. A portion of the substance dissolved, but most of the material remained undissolved as a thick black tar. The acid solution was decanted from tar and poured into 25% aqueous ammonia to spring the free bases and to separate zinc remaining in the material.

A voluminous floculent precipitate was formed which was extracted with benzene. After evaporation of the solvent, the residue was heated for 15 minutes with 6 ml acetic anhydride in order to remove 2-amino-3-methoxybiphenyl, which could have been formed by hydrolysis of unreacted formyl derivative; the almost black solution was poured into 60 ml 1 N HCl.

The black tarry precipitate which separated was filtered, the filtrate made alkaline with 25% aqueous ammonia solution; during this a partially crystalline brown oil separated. It was extracted with benzene, and after evaporation of the solvent, the residue was dissolved in glacial acetic acid. A saturated solution of picric acid in glacial acetic acid was then added. The picrate, a voluminous yellow precipitate, was filtered, washed with glacial acetic acid, and dried in a vacuum dessicator. After repeated recrystallization from glacial acetic acid, we were able to separate the picrate into two different materials: 1-methoxyphenanthridine picrate and 1-hydroxyphenanthridine picrate.

The picrate of 1-methoxyphenanthridine formed fine curved needles, melting at 232°.

4.032 mg substance: 0.439 ml N_2 (18.5°, 748.0 mm). Found %: N 12.55. $C_{14}H_{11}ON \cdot C_6H_3O_7N_3$. Calculated %: N 12.78.

The picrate of 1-hydroxyphenanthridine formed elongated prisms, m.p. 219-220°.

3.376 mg substance: 0.406 ml N_2 (16.0°, 720.6 mm). Found %: N 13.48. $C_{13}H_9ON \cdot C_6H_3O_7N_3$. Calculated %: N 13.21.

Both prepared picrates were heated with concentrated hydrochloric acid. From the solution of hydrochlorides, the bases were separated in free form and purified by distillation.

1-Methoxyphenanthridine was separated from the picrate which melted at 232°; colorless crystals melting at 140-142°.

3.529 mg substance: 10.340 mg CO_2; 1.659 mg H_2O. 6.031 mg substance: 0.349 ml N_2 (18.0°, 748.5 mm). Found %: C 79.91; H 5.26; N 6.69. $C_{14}H_{11}ON$. Calculated %: C 80.38; H 5.26; N 6.69.

1-Hydroxyphenanthridine was separated from the picrate which melted at 219-220°; colorless crystalline substance melting at 186-188°.

4.219 mg substance: 12.301 mg CO_2; 1.791 mg H_2O. 6.008 mg substance: 0.372 ml N_2 (20.5°, 748.0 mm). Found %: C 79.52; H 4.75; N 7.09. $C_{13}H_9ON$. Calculated %: C 80.00; H 4.61; N 7.17.

SUMMARY

1-Methoxyphenanthridine and 1-hydroxyphenanthridine together with a group of new derivatives of biphenyl have been prepared and described.

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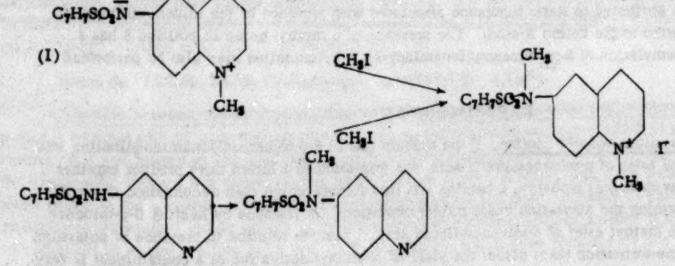
THE BETAINE-LIKE COMPOUNDS FORMED WHEN A PROTON IS DETACHED FROM THE NH-GROUP

VII. REACTION WITH ALKYL AND ACYL HALIDES

A. M. Simonov

The chemical properties of dipolar ions described in our earlier papers [1] have been studied comparatively slightly. We investigated the behavior of these compounds only with acids and water. It was shown that all dipolar ions of this type readily react with acids, even with dilute acetic acid, to form the corresponding quartenary salts. In contrast, hydration occurred only for those compounds we had prepared in whose molecules the nitrogen atom, bearing a negative charge, was linked to p-toluenesulfonic, benzoic, or p-nitrobenzoic acid radicals; in contact with water vapor, betaines of the stated structure added one, sometimes two, molecules of water relatively rapidly. Dipolar ions containing on the negatively charged nitrogen atom dinitrophenyl or picryl groups, i.e., groups which caused a particularly strong displacement of electrons from the negatively charged N-atom, were not converted into bases under the above stated conditions.

It is shown in this paper that dipolar ions of the type studied react with alkyl halides similarly to amino-acid betaines [2] and phenol-betaines of the quinoline type [3]. The alkyl group of the alkyl halide here attaches to the negative N-atom, and the reaction results in formation of a quartenary salt. For instance, methyl-betaine 6-(p-toluenesulfonamido)-quinoline (I) when heated readily combines with one molecule of methyl iodide; to the resulting compound must be attributed the structure of 6-(N-methyl-p-toluenesulfonamido)-quinoline methyl iodide (II), because it is identical to the quartenary salt formed by reaction of 6-(N-methyl-p-toluenesulfonamido)-quinoline (IV) with methyl iodide. Methylbetaine 6-methoxy-8-(p-toluenesulfonamide)-quinoline and methylbetaine 6-(2',4'-dinitroanilino)-quinoline react with methyl iodide in the same manner as does dipolar ion (I). The methyl ester of p-toluenesulfonic acid reacts with betaines in the same way as does methyl iodide.

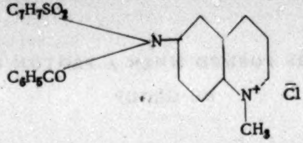


(I)

(III) (IV)

The reaction conditions are dependent on the nature of the radicals attached to the negatively charged N-atom. As in the case of hydration, the more electronophilic the group attached to the negative N-atom, the less readily is an alkyl group attached to that atom. For example, methyl-betaine-6-(p-toluenesulfonamido)-quinoline reacts with methyl iodide at 75-80°, while methylation of the structurally analogous betaine containing a 2,4-dinitrophenyl group instead of the p-toluenesulfonamido one proceeds satisfactorily only at the higher temperature of 125-130°.

The possibility of reaction between betaines of the type under study and acid chlorides is demonstrated using as an example reaction of methyl-betaine 6-(p-toluenesulfonamido)-quinoline (I) with benzoyl chloride: when heated at 120-130°, the quartenary salt (V) is formed.



(V)

Returning to the question about alkylation of methyl-betaine 6-(*p*-toluenesulfonamido)-quinoline, we saw that it would be necessary to prepare 6-(N-methyl-*p*-toluenesulfonamido)-quinoline (IV) in order to explain the structure of the reaction product – quartenary salt (II). For this purpose, we attempted to methylate 6-(*p*-toluenesulfonamido)-quinoline (III). The reaction did not give satisfactory yield, using ordinary methods of alkylation, because the alkylating agent primarily directs itself to the hetero N-atom, and in alkaline medium leads to formation of dipolar ion (I) or the free base corresponding to it. We therefore tried to perform the alkylation using trimethylphenylammonium hydroxide according to the Rodionov procedure [4]; this alkylation agent, successfully used for alkylation of phenols, shows special value in those cases where the compound to be alkylated has a tertiary N-atom, besides the phenolic hydroxyl group, which precludes the possibility of forming the quartenary salt (methylation of morphine). It could be expected that use of this alkylation procedure would be expedient in our case.

The possibility of methylating the $-SO_2NH-$group using trimethylphenylammonium hydroxide was first confirmed, with positive results, on the anilide of *p*-toluenesulfonic acid. The reaction goes according to the equation:

$$ArSO_2NHAr' + [C_6H_5N(CH_3)_3]OH \longrightarrow ArSO_2N(CH_3)Ar' + C_6H_5N(CH_3)_2 + H_2O.$$

In tests performed later to methylate by this procedure 6-(*p*-toluenesulfonamido)-quinoline, we were able to prepare 6-(N-methyl-*p*-toluenesulfonamido)-quinoline with a 60% yield, based on the anilide which was reacted. Consequently, quartenary ammonium bases may be successfully used to alkylate the NH-group of aryl sulfonamides; this alkylation procedure is expedient, evidently, for those compounds whose molecules contain a tertiary nitrogen atom in addition to the substituted sulfonamide group.

In contrast with 6-(*p*-toluenesulfonamido)-quinoline, 8-(*p*-toluenesulfonamido)-quinoline and 6-methoxy-8-(*p*-toluenesulfonamido)-quinoline may be successfully alkylated using ordinary methods. The alkylating agent in these cases reacts primarily with the NH-group because quartenary salt formation takes place with difficulty; it is possible that this may be attributed to steric hindrance associated with presence of the toluenesulfonamido group in the 8-position, i.e, ortho to the hetero N-atom. The presence of a methyl group in position 8 has a similar influence, because methylation of 6-(*p*-toluenesulfonamido)-8-methylquinoline may also be performed using ordinary means [6].

EXPERIMENTAL

6-(N-Methyl-*p*-toluenesulfonamido)-quinoline. If the sodium salt of 6-*p*-toluenesulfonamidoquinoline was heated to 110° with the methyl ester of *p*-toluenesulfonic acid, the formation of a brown tarry product together with copious gas evolution was observed; probably, a betaine was first formed which then decomposed under the reaction conditions. By performing the alkylation under milder conditions, for instance by heating 6-*p*-toluenesulfonamidoquinoline with the methyl ester of *p*-toluenesulfonic acid in acetone solution in presence of potassium carbonate, considerable betaine-formation takes place; the yield of N-methyl derivative as a contaminant is very small. Alkylation using dimethyl sulfate in cold aqueous alkaline solution gave the base almost exclusively. Satisfactory results were obtained only by alkylation with trimethylphenylammonium hydroxide, following Rodionov [4]. An equimolar quantity of alkylating agent was used in the reaction.

0.23 g sodium was dissolved in 5 ml alcohol; to the alcoholate was added a solution of 3.07 g (0.01 mole) trimethylphenylammonium *p*-toluenesulfonate in 8 ml alcohol. Sodium toluenesulfonate, which precipitated on cooling, was filtered off and washed with 4 ml alcohol. To the filtrate was added 2.98 g (0.01 mole) 6-(*p*-toluenesulfonamido)-quinoline. The alcohol was evaporated, the temperature of the reaction mixture increased to 110°, and heating continued at 107-112° for 50 minutes, mixing the mass from time to time. After acidification with acetic acid, dimethyl aniline was removed by steam distillation. The residue was made alkaline with a concentrated solution of caustic, and the caustic solution combined with the oily product formed; it was crystallized by mixing with water and cooling. The water-washed precipitate was dissolved in 3% hydrochloric acid, the solution boiled with carbon, filtered, and made alkaline. The 1.12 g of pinkish-white residue which formed was dissolved in ether in order to separate the small quantity of admixed starting materials, and the ether solution washed with dilute caustic. After vaporization of ether, the residue was crystallized from benzene and from a mixture of petroleum ether and benzene. White crystals, m.p. 121.5-122.5°, readily soluble in alcohol and benzene.

Found %: S 10.14, 10.20. $C_{17}H_{16}N_2O_2S$. Calculated %: S 10.26.

A brownish-pink precipitate of starting material was separated from the caustic solutions on acidification. After crystallization from alcohol, 1.22 g pinkish-white crystals were obtained, m.p. 195.5-197°. Consequently, yield of methylation product, based on 6-p-toluenesulfonamidoquinoline reacted, amounted to 60%.

6-(N-Methyl-p-toluenesulfonamido)-quinoline methyl iodide. 6-(N-Methyl-p-toluenesulfonamido)-quinoline was heated for 1 hour at 45° with an excess of methyl iodide; the excess of the latter was removed by distillation and the residue crystallized from a small volume of methyl alcohol. Very fine pale yellow needles, melting at 220-221° (with decomposition), readily soluble in hot water. The aqueous solution did not become yellow on addition of ammonia, nor did a precipitate form (in contrast with the methyl iodide of 6-p-toluenesulfonamidoquinoline).

Found %: I 27.72. $C_{18}H_{19}N_2O_2SI$. Calculated %: I 27.94.

N-Methylanilide of p-toluenesulfonic acid (prepared in collaboration with D. A. Krivosheya). 2.47 g (0.01 mole) of the anilide of p-toluenesulfonic acid, was methylated at 110° by the Rodionov procedure using trimethylphenylammonium hydroxide, which latter was prepared, as mentioned above, from 3.07 g (0.01 mole) trimethylphenylammonium p-toluenesulfonate. In order to free the compound obtained more completely from starting materials, it was dissolved in ether and washed with a caustic solution. Yield 1.80 g (70%). The product was twice crystallized from alcohol. M.p. 93.5-94.5° (according to the literature, m.p. is 94-95° [7-9]. On acidification of the caustic mother liquor, 0.2-0.4 g initial anilide of p-toluenesulfonic acid was separated.

Reaction between methyl-betaine 6-(p-toluenesulfonamido)-quinoline with methyl iodide. 0.5 g methyl-betaine 6-(p-toluenesulfonamido)-quinoline and 1.2 ml methyl iodide were heated in a sealed tube. The reaction took place very slowly at 60-65° – no change in color of reaction mixture occurred in a half-hour; above 70° the mixture's red color progressively turned yellow. At 75-80°, alkylation required 2.5 hours; at 105°, heating time was reduced to 40 minutes. The yellow crystalline precipitate was filtered, and washed repeatedly with dry benzene. Yield 0.71 g, i.e., almost theoretical. After two crystallizations from methanol, the compound formed pale yellow crystals (fine needles). The product was identical to the methyl iodide of 6-(N-methyl-p-toluenesulfonamido)-quinoline prepared from 6-(N-methyl-p-toluene-sulfonamido)-quinoline (m.p. 219-221°, mixed tests showed no depression).

Found %: I 27.92, 27.70. $C_{18}H_{19}O_2N_2SI$. Calculated %: I 27.94.

Reaction between methyl-betaine 6-(p-toluenesulfonamido)-quinoline and p-toluenesulfonic acid methyl ester. A mixture of 0.30 g methyl-betaine 6-(p-toluenesulfonamido)-quinoline and 0.30 g p-toluenesulfonic acid methyl ester was heated at 130-140° for 1.5 hours. Excess methyl ester was rinsed away with boiling benzene, the hygroscopic product was dissolved in a small volume of boiling water, and 1.5 g sodium iodide in 3 ml water added to the solution. The precipitate (0.40 g) crystallized from methanol as pale yellow needles. The product was the methyl iodide salt of 6-(N-methyl-p-toluenesulfonamido)-quinoline (m.p. 220-221°, no depression was observed in mixed melting point tests using the methyl iodide salts obtained by one of the above described procedures).

Reaction between methyl-betaine 6-(2',4'-dinitroanilino)-quinoline and methyl iodide [preparation of methyl iodide salt of 6-(N-methyl-2',4'-dinitroanilino) quinoline]. 0.25 g methyl-betaine 6-(2',4'-dinitroanilino)-quinoline and 1 ml methyl iodide were heated for 1.5 hours in a sealed tube at 125-130°. A copious precipitate of orange crystals formed. Excess methyl iodide was evaporated, and the residue dissolved in 25 ml hot water. The solution was filtered and 1.5 g potassium iodide added, as a concentrated solution, to the filtrate. The precipitate which separated (0.30 g) was crystallized from methanol. Orange crystals with m.p. 204-205°.

Found %: I 26.82. $C_{17}H_{15}O_4N_4I$. Calculated %: I 27.22.

Reaction between methyl-betaine 6-methoxy-8-(p-toluenesulfonamido)-quinoline and methyl iodide. 0.40 g methyl-betaine 6-methoxy-8-(p-toluenesulfonamido)-quinoline and 1.5 g methyl iodide were heated in a sealed tube at 100° for 1 hour. Yield 0.35 g. Bright yellow crystals (from methanol). Melting temperature was in the 190.0-192.5° range, depending on rate of heating; a mixed melting point test with the methyl iodide salt prepared from 6-methoxy-8-(N-methyl-p-toluenesulfonamido)-quinoline showed no depression.

Found %: I 26.22. $C_{19}H_{21}O_3N_2SI$. Calculated %: I 26.20.

6-Methoxy-8-(N-methyl-p-toluenesulfonamido)-quinoline. 0.80 g 6-methoxy-8-(p-toluenesulfonamido)-quinoline was dissolved in 5 ml 8% potassium hydroxide and 35 ml water; to this solution 1.5 ml dimethyl sulfate was added gradually with vigorous agitation together with enough caustic to maintain alkalinity. At first the reaction mixture was cooled with ice, then the temperature was gradually increased to 15-20°. A yellowish-white precipitate amounting to 0.68 g formed. After crystallization from benzine and from a mixture of petroleum ether and benzene, the reaction product was a white crystalline material, m.p. 152.5-153°.

Found %: S 9.27. $C_{18}H_{18}O_3N_2S$. Calculated %: S 9.36.

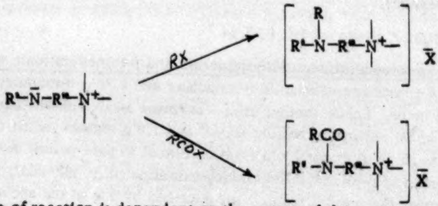
The methyl iodide of 6-methoxy-8-(N-methyl-p-toluenesulfonamido)-quinoline was prepared in poor yield by reaction of methyl iodide and 6-methoxy-8-(N-methyl-p-toluenesulfonamido)-quinoline at 120°. Better results were obtained when 6-methoxy-8-(N-methyl-p-toluenesulfonamido)-quinoline was heated with excess dimethyl sulfate at 100-105° for conversion into methyl-methosulfate and the latter, by reaction with potassium iodide in aqueous solution transformed into the methyl iodide salt. Bright yellow crystals (from methanol), m.p. about 190-192°.

Methylchloride of 6-(N-benzoyl-p-toluenesulfonamido)-quinoline. A mixture of 0.30 g methyl-betaine 6-(p-toluenesulfonamido)-quinoline and 0.20 g freshly distilled benzoyl chloride was heated on an oil bath at 120-130° for 1 hour. The prepared material was washed many times with absolute benzene. Yield 0.41 g (90%). White crystals, very soluble in water, soluble in alcohol. Decomposition temperature approximately 215°. The compound was readily hydrolyzed with the splitting off of a benzoyl group: on addition of aqueous ammonia solution to the material, a yellow color developed, and an orange crystalline precipitate of the hydrate of methyl-betaine 6-(p-toluenesulfonamido)-quinoline rapidly separated.

Found %: S 7.09. 7.09. $C_{24}H_{21}N_2O_3SCl$. Calculated %: S 7.08.

SUMMARY

1. Dipolar ions, prepared when a proton is detached from the NH-group, readily react with alkyl and acyl halides to form quartenary ammonium salts according to the scheme:



The ease of reaction is dependent on the nature of the groups attached to the negative N-atom.

2. Quartenary ammonium bases, proposed by V. M. Rodionov for alkylation of compounds containing hydroxy groups, may also be used for alkylating the NH-group of aryl sulfonamides.

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STUDIES ON AMINOACIDS

II. CATALYTIC REDUCTION OF ESTERS OF OXIMIDO-(ISONITROSO)-CARBOXYLIC ACIDS

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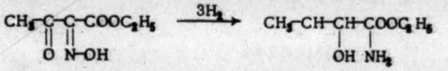
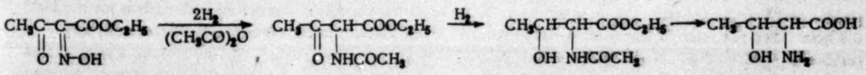
Carbonyl and oximido groups may be reduced [1] to hydroxy or amino groups, respectively, by hydrogen in presence of various catalysts, with the oximido group being more readily reduced than the carbonyl group [2]. For reduction in acid solution, palladium or platinum are used as catalysts; in neutral solution – pyrophoric nickel or other metals.

The present paper is devoted to catalytic reduction reaction studies on both the ethyl ester of isonitrosoacetoacetic acid and the diethyl ester of isonitrosomalonic acid using Raney nickel.



$$CH_3-\underset{\displaystyle O}{\underset{\|}{C}}-\underset{\displaystyle N-OH}{\underset{\|}{C}}-COOC_2H_5 \xrightarrow{3H_2} CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-\underset{\displaystyle NH_2}{\underset{|}{CH}}-COOC_2H_5$$

In as much as isonitrosoacetoacetic ester contains both carbonyl and oximido groups in its molecule, it was quite natural to hope to study the reduction of both of these groups together at one stage. To this end, tests were made and we found it was possible, in neutral medium, to reduce both the oximido and the carbonyl groups at the same time by performing the reaction at 300 atm. and 15-20 minutes. *a*-Amino-*β*-hydroxybutyric acid was obtained with 30-37% yield. Under milder conditions, instead of *a*-amino-*β*-hydroxybutyric acid, the corresponding pyrazine was obtained [4], this proves that only the oximido group was reduced and that the molecules of the aminoacetoacetic ester which formed interact with one another. The severe conditions required for reduction of isonitrosoacetoacetic ester to *a*-amino-*β*-hydroxybutyric acid in neutral solution, together with poor yield, compelled us to search for other procedures for preparation of *a*-amino-*β*-hydroxybutyric acid. Best results were obtained by two-stage reduction of isonitrosoacetoacetic ester [5]:



$$CH_3C-\underset{\displaystyle O}{\underset{\|}{}}\underset{\displaystyle N-OH}{\underset{\|}{C}}-COOC_2H_5 \xrightarrow[(CH_3CO)_2O]{2H_2} CH_3-\underset{\displaystyle O}{\underset{\|}{C}}-\underset{\displaystyle NHCOCH_3}{\underset{|}{CH}}-COOC_2H_5 \xrightarrow{H_2} CH_3\underset{\displaystyle OH}{\underset{|}{CH}}-\underset{\displaystyle NHCOCH_3}{\underset{|}{CH}}-COOC_2H_5 \longrightarrow CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-\underset{\displaystyle NH_2}{\underset{|}{CH}}-COOH$$

it was first reduced to N-acetamido-acetoacetic ester using zinc in an acetic acid solution or using hydrogen in a mixture of acetic acid and acetic anhydride in presence of palladium [6]; the N-acetamidoacetoacetic ester was then reduced in neutral medium using pyrophoric nickel to form the ethyl ester of N-acetamido-*β*-hydroxybutyric acid, which on saponification was transformed into *a*-amino-*β*-hydroxybutyric acid. Overall yield of *a*-amino-*β*-hydroxybutyric acid was 60-65% of theoretical.

Our experimental studies on reduction of carbonyl and oximido groups showed that isonitrosoacetoacetic ester could be directly reduced using Raney nickel to the ester of N-acetamido-*β*-hydroxybutyric acid in one stage, however certain necessary conditions must be maintained. In the first place, an acetylating agent must be present in the reaction mixture to react with the newly formed amino group, and in the second place, the pH of the mixture must be 4.5–5; this is very important for maintaining catalytic activity of pyrophoric nickel. These conditions may be provided by using acetic anhydride as the reaction medium.

By reducing isonitrosoacetoacetic ester with hydrogen in acetic anhydride medium with Raney nickel, we were able to prepare *a*-amino-*β*-hydroxybutyric acid in a 62% yield. When the oximido group is reduced to an amino group, a molecule of water is formed which produces two moles of acetic acid from acetic anhydride. In addition, a mole of acetic acid is formed in acetylating the amino group. Accumulation of three moles of acetic acid changes the pH of the medium, and this interferes with the normal course of the reduction process. Sodium acetate was added to minimize the effect of acetic acid on the reaction. Under these conditions, *a*-amino-*β*-hydroxybutyric acid was obtained with a 72% yield rather than a 62% yield. Contrariwise, by addition of a known excess of acetic acid, the yield of *a*-amino-*β*-hydroxybutyric acid was considerably reduced, at least from the increased quantity of acid added.

We noticed that absorption of hydrogen does not proceed uniformly in reduction of isonitrosoacetoacetic ester. The first two moles of hydrogen are absorbed rapidly at 25-60°; the third mole is absorbed slowly at 90-95°. This phenomenon, wholly concordant with the known facts about the differing reduction behavior of carbonyl and oximido groups, is indicative of the two-stage character of the reduction process. In order to ascertain the reduction conditions in both of these stages separately, we carried out the process of preparing α-amino-β-hydroxybutyric acid in two steps in an acetic anhydride medium using the identical catalyst (Raney nickel). Reduction of isonitrosoacetoacetic ester at 20-25° led to formation of N-acetamidoacetoacetic ester with a 82-83% yield. The latter was reduced at 90-95°, although the reaction proceeded slowly. The resulting ethyl ester of N-acetamido-β-hydroxybutyric acid was saponified, and α-amino-β-hydroxybutyric acid separated with a yield 75.5% of theoretical. We were thus able to show that oximido and carbonyl groups could be reduced in a medium of acetic anhydride using Raney nickel, during which both groups could be reduced separately or both at once.

In addition to reduction of the ester of isonitrosoacetoacetic acid, we investigated reduction of the diethyl ester of isonitrosomalonic acid in an acetic anhydride medium. This compound is usually reduced using zinc dust in acetic acid [7] or by hydrogen in alcoholic medium in the presence of Raney nickel or palladium [8]. In both of these conditions, the diethyl ester of aminomalonic acid becomes acetylated. Under our conditions reduction directly gives the diethyl ester of N-acetamidomalonic acid with a yield 89-90% of theoretical.

We extend thanks to E. M. Elina, S. A. Fuks, E. A. Ignatyeva, and V. V. Ogurtsova for performing the analyses.

EXPERIMENTAL

The ethyl ester of isonitroso-(oximido)-acetoacetic acid was prepared by the Adkins method [3]. Yield, after crystallization of product from toluene, was 73-75% of theoretical. M.p. 58-59°. Diethyl ester of isonitroso-(oximido)-malonic acid was prepared according to a patent [7].

1. Reduction of isonitrosoacetoacetic acid ethyl ester. 31.8 g ethyl ester of isonitrosoacetoacetic acid, 4.5 g freshly fused sodium acetate, 5 g pyrophoric Raney nickel, and 60 ml acetic anhydride were reduced in an autoclave, with agitation, at an initial pressure of 68-70 atm. The reaction was initiated at 15-20° and the temperature gradually brought to 55° in 1-1.5 hours, during this time 12-14 liters of hydrogen were absorbed. Subsequent absorption of the last 4-6 liters of hydrogen took place slowly in 3-4 hours at 95-97°. At the end of hydrogen absorption, the autoclave was cooled and the reaction mixture dumped and filtered; the catalyst was washed with alcohol, the washings added to the main filtrate and evaporated to dryness under vacuum. The residue was then boiled with 100 ml conc. hydrochloric acid for 4 hours, it was boiled with carbon for the last 0.5 hour. The hot solution was filtered and evaporated under vacuum; after vaporization of the acid, the residue was twice taken up with water and evaporated to dryness under vacuum. The dry residue was extracted with 120 ml hot alcohol and diethylamine or aniline added in small portions to the still warm filtered solution until neutral to bromothymol-blue. It was allowed to stand and was filtered the next day. The crude α-amino-β-hydroxybutyric acid was dissolved in 2.5 times its volume of water and precipitated by four volumes of alcohol (based on the water). Yield 72%. M.p. 228-229°. The α-amino-β-hydroxybutyric acid prepared by this procedure contained 21% threonine and 79% allothreonine (microbiological analysis).

Found %: C 40.39; H 7.54; N 11.94. $C_4H_9O_3N$. Calculated %: C 40.31; H 7.62; N 11.76.

Reduction of isonitrosoacetoacetic ester without sodium acetate gave α-amino-β-hydroxybutyric acid with a yield 62% of theoretical.

2. Preparation of N-acetamidoacetoacetic acid ethyl ester. 31.8 g isonitrosoacetoacetic acid ethyl ester, 60 ml acetic anhydride, and 5 g Raney nickel were reduced with hydrogen in an autoclave at 21-25° with an initial pressure of 55-60 atm. The required quantity of hydrogen was absorbed in 4 hours. Reaction mass was removed from the autoclave and filtered. The catalyst was washed on the filter with water. Filtrate was diluted with 250 ml water and extracted several times with chloroform. The chloroform extracts were combined, washed twice with small quantities of water, dried and distilled. The oily residue was dried under vacuum at 60-80° (bath temperature). On cooling, the entire mass crystallized. It was triturated with a small amount of petroleum ether and pressed out on a funnel; melting point of the ethyl ester of N-acetamidoacetoacetic acid was 43-45°. A test mixture with the ethyl ester of N-acetamidoacetoacetic acid prepared by reduction with zinc , melted without depression. Yield 82.8% of theoretical.

3. Reduction of N-acetamidoacetoacetic acid ethyl ester. 37.4 g N-acetamidoacetoacetic acid ethyl ester, 60 ml acetic anhydride, 4.5 g freshly fused sodium acetate, and 5 g Raney nickel were charged into an autoclave and reduced with hydrogen using an initial pressure of 77 atm. Temperature slowly increased to

85-90°, and at this temperature the necessary quantity of hydrogen was absorbed in a 7-8 hour period. At the end of the reaction, the mass was dumped, filtered, and the catalyst washed with 100-120 ml of alcohol. The alcohol washings were combined with the main filtrate and the whole taken to dryness under vacuum. The residue was treated with 100 ml conc. hydrochloric acid and boiled for 4 hours (for the last 0.5 hour with activated carbon. It was filtered and the filtrate evaporated to dryness under vacuum; it was twice more taken up with water and evaporated to dryness each time. The residue was then dissolved in 100 ml boiling alcohol, the solution filtered, the sodium chloride residue on the filter was washed with 30 ml alcohol and the washing added to the main filtrate, and to the still warm alcohol solution diethylamine or aniline was gradually added (bromothymol-blue indicator). The mixture was permitted to stand for 20 hours, filtered, and the residue washed with alcohol and dried. For purification it was dissolved in twice its volume of water and precipitated by 4 times this quantity of alcohol. The melting point of α-amino-β-hydroxybutyric acid was 228-229°. Yield 75.5% of theoretical.

Found %: C 40.12; H 7.60; N 11.62. $C_4H_9O_3N$. Calculated %: C 40.31; H 7.62, N 11.76.

4. Reduction of N-acetamidoacetoacetic ester under the conditions of Experiment 3 but without sodium acetate gave α-amino-β-hydroxybutyric acid with a yield 62% of theoretical.

5. Reduction of N-acetamidoacetoacetic ester in presence of acetic acid. The reaction was run under conditions of Experiment 3, but 34.3 ml acetic acid was used in place of sodium acetate. Yield of α-amino-β-hydroxybutyric acid was 34.4 %. Yield of α-amino-β-hydroxybutyric acid was reduced to 24% of theoretical by addition of 60 ml glacial acetic acid.

6. Diethyl ester of N-acetamidomalonic acid. 105.75 g diethyl ester of isonitrosomalonic acid, 170 ml acetic anhydride, and 15 g Raney nickel were charged into an autoclave and reduced with an initial pressure of 70-80 atm. at 19°; the temperature gradually increased to 73°. The reduction reaction took place in 1-1.5 hours. Quantity of hydrogen absorbed was somewhat greater than theoretical. The autoclave was gradually cooled and the reaction mass removed and filtered. The catalyst was repeatedly washed with alcohol and then with water. The main filtrate, the alcoholic washings, the alcohol with which the autoclave was rinsed, and the water washings were all combined and evaporated to dryness under vacuum. The residue was carefully triturated with carbon tetrachloride and filtered. It was washed once on the filter with carbon tetrachloride. We obtained 109 g diethyl ester of N-acetamido-malonic acid (5 g of this were separated from the carbon tetrachloride), i.e., 89.7% of theoretical. M.p. 94-96°.

Found %: C 49.72; H 6.79; N 6.48. $C_9H_{15}O_5N$. Calculated %: C 49.74; H 6.96; N 6.45.

SUMMARY

It was shown that esters of isonitroso-(oximido)-carboxylic and ketocarboxylic acids can be reduced to the corresponding N-acetamidocarboxylic and N-acetamidohydroxycarboxylic esters using hydrogen with Raney nickel in an acetic anhydride medium.

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SUMMARY

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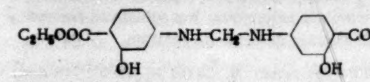
SYNTHESIS OF SEVERAL DERIVATIVES OF PARAAMINOSALICYLIC ACID

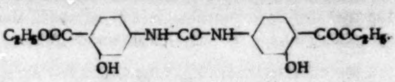
E. S. Golombik and M. N. Shchukina

p-Aminosalicylic acid has acquired great interest at present as an anti-tubercular drug. However, it has an inherent shortcoming – the property of rapid elimination from the organism, in consequence of which large doses, aggregating 18-20 g per day and up to 1 kg per course of therapy, are used for medical treatment of tubercular patients. The development of compounds having the same therapeutic activity as p-aminosalicylic acid but which would be more slowly eliminated from the organism is very important. It was natural to suppose these requirements could be satisfactorily met by using certain derivatives of p-aminosalicylic acid, among which it was fully probable that substances could be found having suitable therapeutic behavior with respect to hydrolysis and other physico-chemical properties and which would be more slowly eliminated from the organism.

According to available literature [1,2] a number of p-aminosalicylic acid derivatives showed anti-tubercular activity in vitro; those derivatives which could readily hydrolyze to it showed activity most similar to p-aminosalicylic acid. However, none of the compounds of this type exceeded p-aminosalicylic acid with regard to activity in vitro [2]. Based on this, the question was raised as to whether bacteriostatic activity of derivatives of p-aminosalicylic acid was dependent on their hydrolysis in the organism. Data [3] published in the past year on the high tubercularstatic activity of p-aminosalicylic acid phenyl ester, both in tests in vitro and in experiments on mice, led us to conclude that the activity of this and possibly other derivatives of p-aminosalicylic acid was manifested by the substance as a whole and not by its hydrolysis product – p-aminosalicylic acid.

In the present paper we describe the preparation and chemical properties of: several N-acyl derivatives of p-aminosalicylic acid and their esters; N-carbalkoxy substituted p-aminosalicylic acids and their esters; [bis-(4-carbethoxy-3-hydroxyphenylamino)]-methane (I); and [bis-(4-carbethoxy-3-hydroxyphenyl)]-urea (II).


(I)


(II)

As a starting material for preparation of derivatives of p-aminosalicylic acid we preferred to use its esters, because the acid is unstable and readily splits out carbon dioxide, particularly in acid media, and in many cases readily becomes tarry.

A convenient method for preparation of p-aminosalicylic acid esters is catalytic reduction, in presence of skeletal nickel catalyst, of the corresponding ester of p-nitrosalicylic acid, esterification of which latter is readily performed using alcohol in presence of sulfuric acid [4]. Esters of p-aminosalicylic acid may also be prepared directly by esterification of the acid with alcohol in presence of excess sulfuric acid [5]. The phenyl ester of p-aminosalicylic acid, the synthesis of which has not been published, was prepared by us by reduction, in presence of skeletal nickel catalyst, of the phenyl ester of p-nitrosalicylic acid. This latter was synthesized by two methods: 1) by action of phosphorous oxychloride on a melt of equimolar quantities of p-nitrosalicylic acid and phenol with subsequent heating of the mixture at 120-130°; 2) boiling in a xylene solution a mixture of equimolar quantities of p-nitrosalicylic acid and phenol in presence of phosphorous pentachloride [6]. The first method was the more suitable, and we were able to prepare the final product with a yield about 57% of theoretical

The N-acyl derivatives were prepared by usual methods – by action of acid chlorides on a solution of p-aminosalicylic acid in pyridine. The methylene-bis-ethyl ester was synthesized by condensation of p-aminosalicylic acid ethyl ester with formalin in an alcoholic medium. Attempts to prepare methylene-bis-p-aminosalicylic acid by condensation of p-aminosalicylic acid with formalin or by saponification of its methylene-bis-ethyl ester led to formation of colored substances, which did not melt on heating to 350°, were readily decarboxylated, and could not be purified. Analytical data on these substances does not permit us to judge their structure.

[Bis-(4-carbethoxy-3-hydroxyphenyl)]-urea was prepared by two methods: 1) condensation of p-aminosalicylic acid ethyl ester with urea at 140-160°; yield about 36% of theoretical [7]; 2) by reaction of phosgene with p-aminosalicylic acid ethyl ester dissolved in boiling benzene or chloroform; yield 93% of theoretical. Reaction temperature was quite important here — only the hydrochloric acid salt of p-aminosalicylic acid ethyl ester was separated when heating was at 40-50°.

The urethanes of p-aminosalicylic acid and its esters were prepared by reaction with the corresponding chlorocarbonic esters. It was most satisfactory to carry out this reaction in a benzene solution in presence of dimethylaniline. Under this condition almost pure materials were prepared in large yield, approaching in some cases 99% of theoretical. Performing this reaction in an alcoholic solution in presence of sodium ethylate [8] led to separation of the corresponding urethane with a yield which did not exceed 50% of theoretical.

EXPERIMENTAL

1. N-Hendecenoyl-p-aminosalicylic acid. To a solution of 3 g p-aminosalicylic acid in 30 ml dry pyridine we added 4 g hendecenoyl chloride dropwise with cooling. The solution obtained was then heated for 3 hours at 40-50°. After evaporation of the pyridine in vacuum, the residue was poured into water; in order to remove unreacted acid chloride the water solution was extracted with ether and treated with acetic acid until acid to litmus. The separated oil was extracted with ether, washed with water and dried over calcined sodium sulfate. The solvent was removed, and the residue which was an oily readily crystallizable material purified by recrystallization from ethyl acetate.

We obtained 6 g (96% of theory) N-hendecenoyl-p-aminosalicylic acid in the form of colorless platelets; m.p. 176° with decomposition; readily soluble in alcohol, ether, acetone, and benzene; insoluble in petroleum ether and water. It gave a violet color with ferric chloride in alcohol solution.

3.839 mg substance: 9.485 mg CO_2; 2.690 mg H_2O. 3.591 mg substance: 8.890 mg CO_2; 2.500 mg H_2O. 7.045 mg substance: 0.280 ml N_2 (20°, 737 mm). Found %: C 67.38, 67.52; H 7.84, 7.79; N 4.49. $C_{18}H_{25}O_4N$. Calculated %: C 67.71; H 7.85; N 4.39.

2. N-Hendecanoyl-p-aminosalicylic acid was prepared in the same manner as N-hendecenoyl-p-aminosalicylic acid. The yield was 10 g (95.3% of theoretical) from 5 g p-aminosalicylic acid. Colorless crystals, m.p. 183-184° with decomposition, readily soluble in alcohol, acetone, and chloroform; less soluble in benzene and ether; and insoluble in water. It gave a violet color with ferric chloride in alcoholic solution.

3.868 mg substance: 9.513 mg CO_2; 2.884 mg H_2O. 8.300 mg substance: 0.335 ml N_2 (21.5°, 718 mm). Found %: C 67.07; H 8.34; N 4.42. $C_{18}H_{27}O_4N$. Calculated %: C 67.29; H 8.41; N 4.36.

3. Isoamyl ester of p-nitrosalicylic acid. A solution of 25 g p-nitrosalicylic acid and 10 ml concentrated sulfuric acid in 200 ml dry isoamyl alcohol was boiled for 24 hours. After evaporating excess alcohol under vacuum, the residue was poured into water. The dark-colored oil which separated was extracted with ether, washed with water and with a saturated solution of sodium bicarbonate, dried over calcined sodium sulfate, and distilled. 22 g yield (63.7% of theoretical). Thick, pale yellow liquid, b.p. 155° at 0.6 mm, readily soluble in most organic solvents, insoluble in water.

4. Isoamyl ester of p-aminosalicylic acid.* A solution of 22 g p-nitrosalicylic acid isoamyl ester in 200 ml alcohol was agitated in a hydrogen atmosphere in presence of 2 g nickel catalyst paste at 50-60° and 15 atm. The calculated quantity of hydrogen was absorbed in 30-45 minutes. After cooling, the solution was filtered and concentrated under vacuum, and the residue poured into water. The almost colorless crystals which formed were separated and recrystallized from 50% aqueous alcohol. Yield 15 g, which corresponds to 77.5% of theoretical. The substance formed colorless rhombic flakes, m.p. 79-80°, readily soluble in most organic solvents.

3.682 mg substance: 8.738 mg CO_2; 2.408 mg H_2O. 6.890 mg substance: 0.389 ml N_2 (21.5°, 732 mm). Found %: C 64.72; H 7.32; N 6.30. $C_{12}H_{17}O_3N$. Calculated %: C 64.57; H 7.62; N 6.28.

5. Phenyl ester of p-nitrosalicylic acid. a) A suspension of 9.2 g p-nitrosalicylic acid (1 mole), 4.7 g phenol (1 mole) and 3.7 g phosphorous pentachloride (0.35 mole) in 100 ml absolute xylene was heated at 90° for 30 minutes, and then for 1.5-2 hours at 120-130° until liberation of hydrogen chloride ended. The reaction

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[*] Using this method, we prepared the ethyl, isopropyl, and isobutyl esters of p-aminosalicylic acid.

mixture remained homogeneous during heating. At the end of the reaction, xylene was vaporized under vacuum, and the oily residue treated with a saturated aqueous solution of sodium bicarbonate. The crystals were separated, dried, and recrystallized from acetic acid. From the sodium bicarbonate solution we recovered 3 g p-nitrosalicylic acid. The yield of p-nitrosalicylic acid phenyl ester was 3.5 g (39.8% of theoretical). Pale yellow crystals, m.p. 148-149°; readily soluble in chloroform, acetone, ethyl acetate, and dioxane; poorly soluble in alcohol and ether; insoluble in water and bicarbonate solution. It gave a violet color with ferric chloride in acetone solution.

5.049 mg substance: 11.151 mg CO_2; 1.632 mg H_2O. 7.215 mg substance: 0.342 ml N_2 (26°, 738.3 mm). Found %: C 60.23; H 3.62; N 5.29. $C_{13}H_9O_5N$. Calculated %: C 60.23; H 3.48; N 5.41.

b) A carefully ground mixture of 2 g p-nitrosalicylic acid (1 mole) and 1 g phenol (1 mole) was melted at 140°. The melt was cooled to 100° and 0.8 g (about 0.5 mole) phosphorous oxychloride added; the mixture was then heated at 120-130° for 2-3 hours until evolution of hydrogen chloride ceased. The mixture remained liquid during heating. After cooling, the dark-colored melt was triturated with water and heated to 50° with a solution of sodium bicarbonate; the precipitate which formed was filtered and recrystallized from acetic acid. We obtained 1.6 g (56.5% of theoretical) p-nitrosalicylic acid phenyl ester, m.p. 148-149°.

6. Reduction of p-nitrosalicylic acid phenyl ester. A solution of 3 g p-nitrosalicylic acid phenyl ester in 50 ml ethyl acetate was agitated in a hydrogen atmosphere in presence of 0.3 g skeletal nickel catalyst at 50-60° and 20 atm. After 30 minutes the calculated quantity of hydrogen had been absorbed. After removal of catalyst, the solution was decolorized with carbon and sodium hydrosulfite, the solvent evaporated under vacuum, and the residue crystallized from ethyl alcohol. Yield of p-aminosalicylic acid phenyl ester was 1.85 g (69.8% of theoretical). Colorless needles, m.p. 147-148.5°, readily soluble in most organic solvents and insoluble in water. A mixed test with the initial p-nitrosalicylic acid phenyl ester melted at 115°.

3.218 mg substance: 8.089 mg CO_2; 1.471 mg H_2O. 7.815 mg substance: 0.423 ml N_2 (20°, 741.2 mm). Found %: C 68.55; H 5.11; N 6.24. $C_{13}H_{11}O_3N$. Calculated %: C 68.12; H 4.80; N 6.11.

7. [Bis-(4-carbethoxy-3-hydroxyphenyl)]-methane. We added 5 ml 36.2% aqueous formalin solution, with stirring, to a solution of 3 g p-aminosalicylic acid ethyl ester (m.p. 115°) in 15 ml ethyl alcohol heated at 50°. In several minutes a colorless precipitate formed, which was separated, washed with small portions of alcohol, and dried in a vacuum dessicator. Yield 2.8 g (90.3% of theoretical). Colorless crystals, m.p. 180-182°; readily soluble in benzene, ether, and acetone; poorly soluble in ethyl acetate, chloroform, and alcohol; and insoluble in water. It crystallized from dioxane, but its melting point then fell to 164°. Consequently the prepared material was analyzed without adequate purification. It gave a color reaction with ferric chloride.

3.701 mg substance: 8.273 mg CO_2; 1.919 mg H_2O. 6.775 mg substance: 0.471 ml N_2 (27.5°, 725 mm). Found %: C 60.96; H 5.80; N 7.52. $C_{19}H_{22}O_6N_2$. Calculated %: C 60.96; H 5.88; N 7.49.

8. [Bis-(4-carbethoxy-3-hydroxyphenyl)]-urea. a) A mixture of 1.8 g p-aminosalicylic acid ethyl ester (2 moles) and 0.3 g urea (1 mole) was heated at 140-160° for a period of 10 hours until evolution of ammonia ceased. After cooling the colored melt was ground up with alcohol. The separated precipitate, after repeated recrystallization from alcohol using activated carbon, formed colorless needles m.p. 215-216°. Yield 0.7 g (36.2% of theoretical); the substance was readily soluble in dioxane and acetone, poorly soluble in benzene, chloroform, ethyl acetate, and ether. A positive test was obtained for the phenolic hydroxyl group using ferric chloride.

3.494 mg substance: 7.530 mg CO_2; 1.610 mg H_2O. 8.305 mg substance: 0.574 ml N_2 (25.5°, 720 mm). Found %: C 58.77; H 5.15; N 7.58. $C_{19}H_{20}O_7N_2$. Calculated %: C 58.76; H 5.15; N 7.22.

b) To a solution of 1.8 g p-aminosalicylic acid ethyl ester in 20 ml absolute benzene (or chloroform) we added 4 ml of a 25% solution of phosgene in absolute benzene. A precipitate formed immediately. The reaction mixture was boiled for 2 hours; on cooling the residue was separated, washed with ether and recrystallized from alcohol. We obtained 1.8 g [bis-(4-carbethoxy-3-hydroxyphenyl)]-urea in the form of colorless needles melting at 215°. A mixed melting point test with a sample of material prepared in the previous experiment showed no depression. Yield was 93.2% of theoretical.

9. N-Carbethoxy-p-aminosalicylic acid. To a vigorously agitated suspension of 3 g p-aminosalicylic acid in 20 ml absolute alcohol at 10-15°, we added 2.2 g ethyl chlorocarbonate and a solution of sodium ethylate (1.5 g sodium in 40 ml absolute alcohol). The reaction mixture was then heated for 1 hour at 40-50° and diluted with water on cooling. The aqueous solution was neutralized with 10% hydrochloric acid. The precipitate was separated

and recrystallized from 50% aqueous alcohol with use of activated carbon. Yield 2.2 g (50% of theoretical). The substance formed colorless needles, m.p. 210°; readily soluble in alcohols, ether, ethyl acetate, and acetone; less soluble in benzene and petroleum ether; and insoluble in water. In alcohol solution it gave a violet color with ferric chloride.

3.594 mg substance: 7.044 mg CO_2; 1.619 mg H_2O. 8.700 mg substance: 0.500 ml N_2 (23°, 733 mm). Found %: C 53.45; H 5.04; N 6.39. $C_{10}H_{11}O_5N$. Calculated %: C 53.34; H 4.89; N 6.22.

10. N-Carbethoxy-p-aminosalicylic acid ethyl ester. a) To a solution of 3.6 g (1 mole) p-aminosalicylic acid ethyl ester in 40 ml absolute ethyl alcohol, agitated and cooled to 5°, we gradually added 2.2 g (1 mole) ethyl chlorocarbonate and a solution of sodium alcoholate (0.7 g sodium in 30 ml absolute alcohol). The latter was added at such a rate that the temperature did not exceed 15°. The reaction mass was then stirred for 2 hours at room temperature, sodium chloride separated, excess alcohol evaporated under vacuum, and the residue recrystallized from alcohol. The ethyl ester of N-carbethoxy-p-aminosalicylic acid was prepared in the form of colorless prisms, m.p. 149-151°; readily soluble in acetone and ethyl acetate, moderately soluble in alcohols, less soluble in benzene and ether, and insoluble in water. Yield 1.7 g, corresponds to 33.8% of theoretical. A positive test was obtained for the phenolic hydroxyl group using ferric chloride.

3.648 mg substance: 7.644 mg CO_2; 1.908 mg H_2O. 6.845 mg substance: 0.344 ml N_2 (23°, 727 mm). Found %: C 56.59; H 5.79; N 5.54. $C_{12}H_{15}O_5N$. Calculated %: C 56.92; H 5.93; N 5.53.

11. N-Carbethoxy-p-aminosalicylic acid isobutyl ester was prepared in the same way as N-carbethoxy-p-aminosalicylic acid ethyl ester. Because the substance was soluble in benzene, it was separated in the following manner: the reaction mixture was treated with a 5% hydrochloric acid solution for removal of excess dimethyl aniline, washed with water, and dried over calcined sodium sulfate. The residue after removal of solvent was recrystallized from ethyl alcohol. From 1.1 g p-aminosalicylic acid isobutyl ester we obtained 1.4 g (94.5% of theoretical) N-carbethoxy-p-aminosalicylic acid isobutyl ester as colorless octahedral needles, m.p. 132-134° (from alcohol); readily soluble in most organic solvents, insoluble in water; it gave a color reaction with ferric chloride in alcoholic solution.

4.618 mg substance: 10.099 mg CO_2; 2.839 mg H_2O. Found %: C 59.64; H 6.87. $C_{14}H_{19}O_5N$. Calculated %: C 59.79; H 6.76.

12. N-Carbethoxy-p-aminosalicylic acid isopropyl ester was prepared similarly to the foregoing. Yield 1.3 g, which corresponds to 94.8% of theoretical. The substance formed colorless pyramids, m.p. 143-145° (from alcohol); readily soluble in acetone, benzene, and alcohol; insoluble in ether, petroleum ether, and water; it gave an intense violet color with ferric chloride.

3.540 mg substance: 7.598 mg CO_2; 2.089 mg H_2O. Found %: C 58.54; H 6.60. $C_{13}H_{17}O_5N$. Calculated %: C 58.43; H 6.37.

13. The isobutyl ester of N-carbisobutoxy-p-aminosalicylic acid was prepared in the same way as was the previous ester. Yield 77.5% of theoretical. Colorless rhombic flakes (from hexane), m.p. 65-67°; readily soluble in most organic solvents and insoluble in water; it gave an intense violet color with ferric chloride.

4.268 mg substance: 9.770 mg CO_2; 2.968 mg H_2O. Found %: C 62.43; H 7.78. $C_{16}H_{23}O_5N$. Calculated %: C 62.14; H 7.44.

14. The isobutyl ester of N-carbisopropoxy-p-aminosalicylic acid was prepared in the same manner as the previous esters with a yield 95% of theoretical. It formed cubic prisms (from petroleum ether, 45-65° fraction), m.p. 72-74°; readily soluble in most organic solvents, insoluble in water.

3.928 mg substance: 8.770 mg CO_2; 2.530 mg H_2O. Found %: C 60.89; H 7.21. $C_{15}H_{21}O_5N$. Calculated %: C 61.02; H 7.12.

15. The isopropyl ester of N-carbisopropoxy-p-aminosalicylic acid was prepared in the same manner. Yield 1.40 g, corresponding to 97.1% of theoretical. Colorless cubic prisms with m.p. 90-92° (from hexane); readily soluble in most organic solvents and insoluble in water.

4.580 mg substance: 10.068 mg CO_2; 2.767 mg H_2O. Found %: C 59.95; H 6.76. $C_{14}H_{19}O_5N$. Calculated %: C 59.79; H 6.76.

16. The isopropyl ester of N-carbisobutoxy-p-aminosalicylic acid was prepared in the very same way as the previous ester. The yield was 99% of theoretical. Colorless flakes with m.p. 77-79° (from hexane): readily soluble in most organic solvents and insoluble in water.

3.690 mg substance: 8.302 mg CO_2; 2.400 mg H_2O. Found %: C 61.36; H 7.28. $C_{15}H_{21}O_5N$. Calculated %: C 61.02; H 7.12.

SUMMARY

A series of derivatives of p-aminosalicylic has been synthesized namely: its esters, N-carbalkoxy-p-aminosalicylic acids and their esters, N-acyl-p-aminosalicylic acids, [bis-(4-carbethoxy-3-hydroxyphenyl)]-urea, and [bis-(4-carbethoxy-3-hydroxyphenylamino)]-methane.

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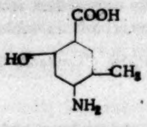
* See Consultants Bureau translation page 947.

SYNTHESIS OF HOMOLOGS OF PARAAMINOSALICYLIC ACID

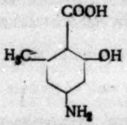
M. N. Shchukina, Yu. V. Markova, and A. M. Pozharskaya

In the comparatively short time since discovery of the antitubercular activity of p-aminosalicylic acid, a large number of studies have been made on synthesis and biological investigation of many of its derivatives and analogs. However, homologs of p-aminosalicylic acid containing an alkyl group on the aromatic nucleus have not been described in the chemical literature until the present time. It seemed of interest to synthesize such compounds in order to investigate the effect of side chains on the anti-tubercular activity of compounds of this type, because the introduction of alkyl groups into the aromatic nucleus of several phenols, for example the derivatives of resorcinol and resorcylic acid, increases their anti-tubercular activity, reaching a maximum with the hexyl-substituted derivative [1].

In the present paper we describe synthesis of the simplest alkyl derivatives of p-aminosalicylic acid – 3-methyl-4-amino-6-hydroxybenzoic acid (I) and 2-hydroxy-4-amino-6-methylbenzoic acid (II):



(I)



(II)

We prepared 3-methyl-4-amino-6-hydroxybenzoic acid (I) starting with p-nitro-o-toluidine, by subjecting its acetyl derivative to catalytic reduction in an ethyl acetate medium in presence of skeletal nickel catalyst. By diazotization accompanied by saponification, 2-acetamido-4-nitrotoluene was converted into 2-amino-4-hydroxytoluene, which was then heated in an autoclave with carbon dioxide and anhydrous potassium carbonate.

The starting material for synthesis of 2-hydroxy-4-amino-6-methylbenzoic acid (II), 3-hydroxy-5-nitrotoluene, was prepared by us from p-acetotoluide via 3,4-dinitro-p-toluidine [2], eliminating the amino group by diazotization [3], reduction to 3-amino-5-nitrotoluene [4], and diazotization [5]. The 3-hydroxy-5-nitrotoluene prepared in this manner was reduced, in the presence of skeletal nickel catalyst in an alcoholic medium, to 3-hydroxy-5-aminotoluene which was then carboxylated under the same conditions as were used for 2-amino-4-hydroxytoluene.

The carboxyl group position in the methyl-p-aminosalicylic acids prepared cannot be given incontravertibly, because theoretical possibilities exist, that carbon dioxide can add in the 3 position to 2-amino-4-hydroxytoluene and in the 4 or 6 positions of 3-hydroxy-5-aminotoluene. However, using results obtained in carboxylation of m-aminophenol, where the carboxyl group predominately adds para to the amino group, we may presume that the carboxyl group is likewise para to the amino group in the acids we prepared, i.e., corresponding to formulas (I) and (II).

EXPERIMENTAL

2-Acetamido-4-aminotoluene. 25 g 2-acetamido-4-nitrotoluene in 100 ml ethyl acetate was hydrogenated in presence of 2.5 g skeletal nickel catalyst in an autoclave at 40° and 60 atm pressure for 1 hour. The reaction product was separated from catalyst, solvent evaporated under vacuum, and the precipitate which separated recrystallized from alcohol. Yield 22.7 g (90.5% of theoretical); m.p. 139-140°.

2-Amino-4-hydroxytoluene. To 10 g 2-acetamido-4-aminotoluene in 10 ml concentrated hydrochloric acid and 75 ml water, we added at 65° a solution of 4.5 g sodium nitrate in 80 ml water during a 30 minute period. The reaction mixture was then heated at 65° for 30 minutes with stirring. The resulting solution was filtered and concentrated under vacuum. 75 ml 25% hydrochloric acid solution was added to the residue and refluxed for 15-20 minutes. The solution was cooled, neutralized with potassium bicarbonate, and extracted with ether. After drying the ether extract with sodium sulfate, the ether was vaporized, and the residue recrystallized from water. 3.2 g 2-amino-4-hydroxytoluene (about 43% of theoretical) was obtained: m.p. 144-145°.

Carboxylation of 2-amino-4-hydroxytoluene. 2 g 2-amino-4-hydroxytoluene was mixed with 20 g finely divided calcined potassium carbonate; the mixture was heated in an autoclave for 6 hours at oil bath temperature (175-178°) with a 50-60 atm carbon dioxide pressure. After cooling, the reaction product was dissolved in water, treated with sodium hydrosulfite, filtered, and carefully acidified with hydrochloric acid while adequately cooled. The separated acid was filtered by suction, washed with water and purified by solution in sodium bicarbonate with subsequent liberation of the aminoacid by use of acetic acid.

We obtained 2.3 g 2-hydroxy-4-amino-5-methylbenzoic acid (about 85% of theoretical). M.p. 145-146° (with decomposition). Fine needle-like crystals, lightly rose colored. Soluble in bicarbonate, ether, and benzene; poorly soluble in ethyl acetate and cold water.

6.125 mg substance: 0.430 ml N_2 (23°, 743 mm). Found %: N 7.98. $C_8H_9O_3N$. Calculated %: N 8.38.

3-Hydroxy-5-aminotoluene. 10 g 3-hydroxy-5-nitrotoluene (prepared from p-acetotoluide) was dissolved in 60 ml ethyl alcohol and hydrogenated in presence of 6 g skeletal nickel catalyst at normal pressure and room temperature. After removal of catalyst and vaporization of alcohol under vacuum, the residue was treated with 10% hydrochloric acid. The free base was separated from the resulting solution of 3-hydroxy-5-aminotoluene hydrochloride by addition of dry sodium bicarbonate. After washing with water and drying in a vacuum dessicator, we obtained 5.1 g 3-hydroxy-5-aminotoluene. M.p. 137-138°. Needles, very rapidly turning dark violet. The material was readily soluble in hot water, alcohol and acetone; poorly soluble in ether; and insoluble in benzene.

6.270 mg substance: 0.628 ml N_2 (28°, 725 mm). Found %: N 10.84. C_7H_9ON. Calculated %: N 11.38.

The substance was not purified further in view of its ease of oxidation.

Carboxylation of 3-hydroxy-5-aminotoluene. A mixture of 2 g 3-hydroxy-5-aminotoluene and 20 g calcined potassium carbonate was heated for 7-8 hours in an autoclave at 170-180° with a 50-60 atm carbon dioxide pressure. After cooling, the contents of the tube were dissolved in water and carefully acidified with hydrochloric acid. The separated acid was filtered by suction, washed with water, and purified by conversion into the sodium salt by action of an aqueous solution of sodium bicarbonate followed by subsequent separation of the free acid by treating the sodium salt with hydrochloric acid. We obtained 1.85 g 2-hydroxy-4-amino-6-methylbenzoic acid. M.p. 127.5-128°. The material decarboxylated at its melting point.

It was soluble in bicarbonate, chloroform, petroleum ether, and benzene; poorly soluble in ether, ethyl acetate, and cold water.

7.010 mg substance: 0.539 ml N_2 (27°, 725.5 mm). Found %: N 8.54. $C_8H_9O_3N$. Calculated %: N 8.38.

SUMMARY

2-Hydroxy-4-amino-5-methylbenzoic acid was synthesized via a series of intermediate materials starting from 2-amino-4-nitrotoluene. 2-Hydroxy-4-amino-6-methylbenzoic acid was prepared starting with 3-hydroxy-5-nitrotoluene.

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AMIDINES OF AMINO ACIDS

1. SYNTHESIS OF IMINO-ETHERS OF AMINO ACIDS

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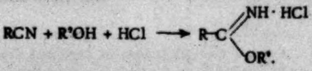
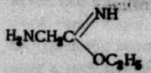
Representatives of many types of imino-ethers are known: aromatic, aliphatic, and heterocyclic, with various functional and hydrocarbon substituents on the radical R. The classical method for synthesis of these compounds, which enabled preparation of the overwhelming majority of imino-esters referred to, involves treatment of an equimolar mixture of the proper nitrile and absolute alcohol with dry hydrogen chloride [1]:



$$RCN + R'OH + HCl \longrightarrow R{-}C\begin{matrix}\diagup NH\cdot HCl\\ \diagdown OR'\end{matrix}$$

As a rule, the imino-ether salts produced as a result of the reaction are colorless crystalline compounds which readily react with various substances (water, alcohol, amines, etc.). Because of their high reactivity, excess alcohol must be avoided in preparation of imino-ether salts, very carefully dried reagents must be used, and the reaction must be performed at sufficiently low temperatures.

However, despite wide applicability of this method for synthesis of many imino-ethers, it is not generally possible to prepare imino-ethers of amino acids from the corresponding amino-nitriles in this manner. This is explained, in most cases, by the slight solubility of amino-nitrile salts in alcohol (in treating a mixture of equimolar quantities of amino-nitrile and alcohol with hydrogen chloride, as is required by this method, an amino-nitrile salt forms at first which precipitates from solution and very incomplete conversion to imino-ether occurs [2]). The situation is not improved by use of other non-hydroxy-containing solvents (benzene, chloroform, ether), because amino-nitrile salts are likewise poorly soluble in them usually; (in fact, use of similar solvents proved successful in synthesis of N-acyl derivatives of amino acid imino-ethers [3,5]). In this connection one should mention the work of Curcius [4]. The latter, treating aminoacetonitrile with a large excess of absolute ethyl alcohol saturated with hydrogen chloride, was able to show that the precipitate which spontaneously separated from the reaction mixture was aminoacetiminoethyl ether dihydrochloride:



$$H_2NCH_2C\begin{matrix}\diagup NH\\ \diagdown OC_2H_5\end{matrix}\cdot 2HCl.$$

In repeating this work, Freidenberg [5] prepared this compound in 18% yield (in contrast to the 40% yield reported by Curtius). The low yield was due to the relatively poor solubility of aminoacetonitrile hydrochloride in an alcoholic solution of hydrogen chloride, because of which some of the starting material was recoverable unchanged.

We found that aminoacetiminoethyl ether could be easily prepared with a significantly good yield (80%) by using excess of methyl alcohol saturated with hydrogen chloride to ensure complete solubility of the initial aminoacetonitrile hydrochloride. However, a similar procedure for homologs of aminoacetonitrile did not as a rule lead to spontaneous precipitation of the imino-ether salt, as was observed in the above instance; consequently, we decided to use a small excess of ethyl ether to precipitate the reaction product, based on the almost complete insolubility of imino-ether salts in this solvent.

In using this method, questions inevitably arose on whether the length of reaction time (prior to precipitation by ether) was suitable and whether, in principle, it was possible to obtain sufficiently pure material by this method (purification of imino-ether salts, because they are so labile, is a difficult operation associated with large losses). It was necessary to consider whether salts of the initial amino-nitrile (if reaction were incomplete), or decomposition products of the imino-ether, would be separated together with the imino-ether salt on addition of ether to the reaction mixture.

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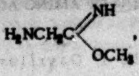
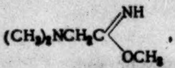
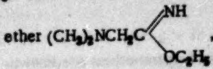
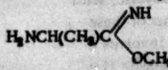
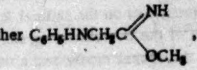
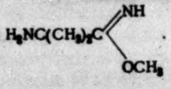
*Deceased.

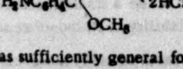
Tests were performed [using the dihydrochloride of dimethylaminoacetonitrile, $(CH_3)_2NCH_2CN$, as a starting material for a series of experiments] which showed that almost complete conversion of the initial nitrile into an imino-ether occurred in a 10 minute reaction time. Product purity was not decreased with a one hour reaction time, but increasing the time to 3 hours significantly reduced imino-ether purity. Further extension of the reaction period resulted in complete decomposition of the imino-ether salt (Table 2). Using this improved method, we were able to prepare, as dihydrochlorides, the following α-amino acid imino-ethers: aminoacetiminomethyl ether  $H_2NCH_2C(=NH)OCH_3$, dimethylaminoacetiminomethyl ether  $(CH_3)_2NCH_2C(=NH)OCH_3$, dimethylaminoacetiminoethyl ether  $(CH_3)_2NCH_2C(=NH)OC_2H_5$, alanineiminomethyl ether  $H_2NCH(CH_3)C(=NH)OCH_3$, N-phenylglycineiminomethyl ether  $C_6H_5HNCH_2C(=NH)OCH_3$, and aminoisobutyriminomethyl ether  $H_2NC(CH_3)_2C(=NH)OCH_3$.

The compounds we prepared were colorless crystalline materials, which decomposed rather readily to the corresponding amides on storage. This was particularly rapid for dimethylaminoacetiminoethyl ether hydrochloride. To follow imino-ether decomposition qualitatively as it occurred, we used this test: addition of a copper salt solution together with a small quantity of alkali to freshly prepared imino-ether gave a blue solution; the more the imino-ether decomposed into the corresponding amide, the more and more violet was the solution color on addition of these reagents, reaching a lilac-violet with amides.

Because of the reactivity and instability of these compounds a number of precautions were necessary for their synthesis, namely: isolation from atmospheric moisture and absolute dryness of the reagents (alcohol, ether). Instability of these compounds with time forced us to conduct their analysis, and to perform further studies, immediately on preparation, after drying in a vacuum dessicator over sulfuric acid or solid sodium hydroxide.

In preparing imino-ether salts from β-dimethylaminopropionitrile under the same conditions as were used for an α-aminonitrile, we noted that the former reacted noticeably more slowly; using a 10 minute reaction time, material separated after addition of ether contained a considerable portion of unchanged nitrile salt; only by increasing the reaction time to one half hour were we able to obtain the desired imino-ether in sufficiently high yield.

The difference in the rate of formation of imino-ethers of α- and β-aminonitriles undoubtedly is caused by activation of the nitrile group of the former by the adjacent α-amino group. The effect of the latter in β-dimethylaminopropionitrile, in consequence of the greater separation, must be regarded as being at a comparatively lower level. An instance of similar activation, but to higher levels, was shown by the compound trichloracetonitrile, which gave the corresponding imino-ether on treatment with alcohol (without use of hydrogen chloride) [6], – this reaction is not known for ordinary nitriles.

By applying our improved method to an aromatic aminonitrile – m-aminobenzonitrile – we were able to prepare m-aminobenziminomethyl ether dihydrochloride:  $H_2NC_6H_4C(=NH)OCH_3 \cdot 2HCl$.

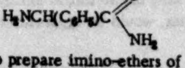
Thus, the above method of synthesis may be regarded as sufficiently general for preparation of imino-ethers of amino acids; in actual fact, like the classical method, it has several limitations. For example, in attempts to convert α-phenylglycinenitrile into the corresponding imino-ether, instead of the latter, the hydrochloride of α-phenylglycineamide  $H_2NCH(C_6H_5)C(=O)NH_2$ was separated quantitatively. This phenomenon was also observed in tests to prepare imino-ethers of certain α-substituted nitriles by the classical method. Steinkopf [7], who also investigated a series of substituted acetonitriles from this same point of view, obtained, by carrying out the reaction, the results given in Table 1.

TABLE 1

Compound	Result of reaction
$ClCH_2CN$	Imino-ether salt
$BrCH_2CN$	
ICH_2CN	
O_2NCH_2CN	Amide
Cl_3CCN	
Br_3CCN	
Cl_2CHCN	
O_2NCCl_2CN	
Br_2CHCN	Mixture of Amide and imino-ether salt
$O_2NC(CH_3)_2CN$	Imino-ether salt

The data definitely show that the reaction products are determined both qualitatively and quantitatively by the negative substituents; this was also noted by Steinkopf.

The anomalous result obtained by us in attempting to prepare an imino-ether salt from phenylglycinenitrile is in accordance with this data: introduction of a phenyl group into nitrile molecule which already has an electronegative substituent in the α-position – the amino group – increases the effect of the latter sufficiently strongly so that the reaction leads to formation of amides instead of imino-ether salts.

Replacement of the phenyl group by a methyl group, which has an electropositive character, results, as might have been expected, in formation of normal reaction products – imino-ether salts (alanineiminomethyl ether).

Undoubtedly, the difference in reaction course between nitroacetonitrile and nitroisobutyronitrile may be explained in a similar manner (Steinkopf was inclined to regard the possible existence of the nitro group of the former in an aci-form as the reason for the difference), namely, the presence of two methyl groups in the nitroisobutyronitrile molecule compensates for the electronegative effect of the nitro group to such an extent that imino-ethers are formed during the reaction.

EXPERIMENTAL

I. Aminoacetiminomethyl (glycineiminomethyl)-ether

Methyleneaminoacetonitrile [8]. This was prepared from 270 g ammonium chloride, 750 g formalin (specific gravity 1.078), and 245 g sodium cyanide. Yield 225 g. After recrystallization from water it melted at 128.5-129°.

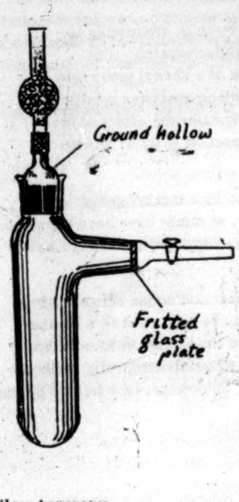
Aminoacetonitrile hydrochloride [4]. This was made by treating 10 g methyleneaminoacetonitrile with 150 ml of a 1 N solution of hydrogen chloride in ethyl alcohol. 8.5 g of the nitrile salt were separated. Another 4 g of the substance were separated from the mother liquor using ether. Methyl alcohol may be used in preparation of the substance instead of ethyl alcohol: 22 g methyleneaminoacetonitrile was wetted with a small quantity of methyl alcohol and 170 ml of a 2 N solution of hydrogen chloride in methyl alcohol gradually added with stirring. The material rapidly went into solution, and the mixture was permitted to stand for a day. The crystals which had separated in that time were removed by suction filtration, washed with ether, and dried in a vacuum dessicator. Yield 19.5 g (63.5% of theoretical). An additional 7-8 g of material could be recovered by concentration of the mother liquor or by addition of ether. Recrystallization from five times its volume of methyl alcohol gave a pure product, m.p. 173-175° (with decomposition).

Exclusion of atmospheric moisture was essential in working with aminoacetonitrile hydrochloride because the substance was highly hygroscopic.

Aminoacetiminomethyl ether dihydrochloride. 2 g aminoacetonitrile hydrochloride was triturated with a small amount of absolute methyl alcohol (protected from atmospheric moisture); to this was added, with simultaneous cooling, 50 g absolute methyl alcohol which had been saturated with dry hydrogen chloride at 10°. Rapid solution occurred on vigorous agitation, and in 2-3 minutes a voluminous precipitate began to form. When precipitation begins the nitrile salt should be almost completely dissolved; this is normally the case if trituration is thorough; otherwise the solution should be quickly filtered under reduced pressure with atmospheric moisture excluded. It was most convenient to perform the reaction in a N. I. Gavrilov apparatus (see sketch); this apparatus is fitted with a calcium chloride tube and has an integral filter which may be connected to a vacuum receiver. The filter plate had to be rather porous (no.1-2). The precipitate which formed in an hour was filtered, washed with absolute ether, and dried in a vacuum dessicator. Yield 2.6 g (80% of theoretical). M.p. 198-199° (with decomposition).

0.1828 g, 0.2114 g substance: 22.85 ml, 26.40 ml 0.1 N H_2SO_4 (Kjeldahl). 0.1972 g, 0.2008 g substance: 24.0 ml, 25.00 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 17.49, 17.48; Cl 44.28, 44.19. $C_3H_{10}ON_2Cl_2$. Calculated %: N 17.39; Cl 44.10

Colorless flakes, readily soluble in water with evolution of heat. It was difficultly soluble in alcohol and insoluble in ether.



Gavrilov Apparatus

After three weeks storage, recrystallization of the imino-ether salt from methyl alcohol gave colorless crystals with m.p. 207-208°. Both before and after recrystallization this substance gave an intense violet color when treated with copper salts in alkaline solution. This material was soluble in water without evolution of heat, poorly soluble in alcohol, and insoluble in ether.

0.1460 g, 0.1749 g substance: 26.3 ml, 31.4 ml 0.1 N H_2SO_4 (Kjeldahl). 0.1832 g substance: 16.55 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 25.22, 25.13; Cl 32.07. $C_2H_7ON_2Cl$. Calculated %: N 25.22, 25.13; Cl 32.12.

The material thus was aminoacetamide hydrochloride as shown by its properties and the analytical data (m.p. 186-189° [9]).

II. Dimethylaminoacetiminomethyl ether

Dimethylaminoacetonitrile. This was prepared from 110 ml 22.8% aqueous dimethylamine solution, 50 ml formalin, and 30 g potassium cyanide. The yield of the nitrile was 26 g, m.p. 135-138°. By treatment of dimethylaminoacetonitrile in ether solution with hydrogen chloride, we prepared the nitrile salt, which after recrystallization from methyl alcohol had a m.p. of 150-151.5°.

Dimethylaminoacetiminomethyl ether dihydrochloride. To 3 g dimethylaminoacetonitrile hydrochloride was added 50 ml absolute methyl alcohol which had been saturated cold (cooled with ice water) with dry hydrogen chloride. The reaction mixture was shaken, and after complete solution of the nitrile salt occurred (which generally took 2-3 minutes), was permitted to stand for 20 minutes. At the end of this time, twice the volume of absolute ether was added; this produced a voluminous precipitate. The latter was allowed to stand for a half-hour and filtered by suction, washed with absolute ether, and dried in a vacuum dessicator. Yield 3.7 g (79% of theoretical), colorless solid with a mother-of-pearl luster. M.p. 195-197°.

0.2112 g substance: 22.50 ml 0.1 N H_2SO_4 (Kjeldahl) 0.2188 g, 0.2010 g substance: 23.25 ml, 21.35 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 14.91; Cl 37.72, 37.7. $C_5H_{14}ON_2Cl_2$. Calculated %: N 14.81; Cl 37.62.

The substance was readily soluble in water (with decomposition) and less soluble in methyl alcohol.

After lengthy storage, the substance when recrystallized from methyl alcohol yielded colorless crystals with m.p. 206-207°, which were readily soluble in water and methyl alcohol and insoluble in ether. A violet color was obtained by treatment of this material with an aqueous solution of divalent copper in the presence of alkali.

6.035 mg, 4.825 mg substance: 7.605 mg, 6.100 mg CO_2; 4.335 mg, 3.390 mg H_2O. Found %: C 34.37, 34.48; H 8.03, 7.88. $C_4H_{11}ON_2Cl$. Calculated %: C 34.65; H 7.97.

It therefore appeared that this material was dimethylaminoacetamide hydrochloride.

Effect of increase in time for reaction of methyl alcohol (saturated with hydrogen chloride) and dimethylaminoacetonitrile hydrochloride on dimethylaminoacetiminomethyl ether dihydrochloride formation. In order to study the velocity of imino-ether formation as well as their stability in the reaction mixture with time, we performed a series of tests in which we varied reaction time holding all other conditions constant. In these tests, we treated 2 g dimethylaminoacetonitrile hydrochloride with 35 ml absolute methyl alcohol which had been saturated cold (cooled with ice water) with hydrogen chloride. The reaction mix was agitated, with cooling, until the starting nitrile salt was dissolved and was let stand in ice water for a predetermined time, at the end of which we added double the volume of absolute ether to precipitate the reaction product. The reaction mixture was maintained cold in ice water for 0.5-1 hour, depending on the ease of separation of the precipitate; the latter was then filtered by suction, washed several times with absolute ether and dried in a vacuum dessicator for 3 hours. All of these operations were performed with atmospheric moisture excluded. Samples for analysis were taken immediately after drying.

Reaction times (after solution of the nitrile salt) were: 10 minutes, 1,3,7, and 20 hours. Test data are given in Table 2.

TABLE 2

Reaction Time	Yield of imino-ether salt (in grams)	Analysis of reaction product (in %)		Notes
		Nitrogen (Kjeldahl)	Chlorine (Volhard)	
10 minutes	2,5	14.61	37.72	
1 hour	2.6	14.78	37.58	Theoretical composition: Cl 37.6% N 14.81%
3 hours	2.5	15.15	37.6	
7 hours	1.9	18.82	31.86	
20 hours	On addition of ether, ammonium chloride was quantitatively separated			

III. Dimethylaminoacetiminoethyl ether dihydrochloride.

20 ml absolute ethyl alcohol which had been saturated cold with dry hydrogen chloride was added to 1 g dimethylaminoacetonitrile hydrochloride. On continued stirring with cooling, the nitrile salt gradually went into solution. Solution took place considerably more slowly than in preparation of the methyl homolog, and was complete in about a half-hour. After the solution had stood for an hour (cooled in ice water), we added twice its volume of absolute ether; a colorless oil, which gradually became completely crystalline, soon began to separate on the bottom of the reaction vessel. After suction filtration and washing with absolute ether, we obtained 1.35 g (81% of theoretical) of colorless hygroscopic crystals.

The material reacted with water with liberation of heat, and rapidly decomposed on storage in a vacuum dessicator; the freshly prepared substance did not form a violet copper complex, but after 1-2 hours of storage the violet color of the complex was clearly evident (transformation into dimethylaminoacetamide). Because it was not possible to analyze this substance for the above reason, we demonstrated that it was really dimethylaminoacetaminoethyl ether dihydrochloride by treating 1 g of freshly prepared substance with a solution of 1 ml dry aniline in 10 ml ether. The precipitate quickly re-formed, turned to a viscous liquid and then solidified again; the reaction mix was allowed to stand for 2 days after which the precipitate was filtered by suction and washed with ether. Yield 1.25 g. This material was dissolved in methyl alcohol and subsequently precipitated with ether to yield a substance which gave, with an alcoholic solution of picric acid, yellow crystals, having m.p. 217-218°, which did not depress the melting point of N-phenyldimethylaminoacetamidine dipicrate.

IV. Aminoisobutyriminomethyl ether.

Aminoisobutyronitrile hydrochloride [11]. Aminoisobutyronitrile was prepared from 55 g ammonium chloride, 74 ml acetone, and 70 g potassium cyanide. Yield 43 g; m.p. 70-71°.

Aminoisobutyronitrile hydrochloride was prepared by passing hydrogen chloride into an ether solution of the nitrile until it reacted acid to Congo red. M.p. 147-149°. If necessary, the substance was recrystallized. For this we dissolved it in a small quantity of methyl alcohol and then added 4 times its volume of acetone; very well-formed crystals of aminoisobutyronitrile hydrochloride gradually began to separate.

Aminoisobutyroiminomethyl ether dihydrochloride. We added 35 ml absolute methyl alcohol which had been saturated when cold with hydrogen chloride to 2 g aminoisobutyronitrile hydrochloride. On continued cooling in ice water, with stirring, the nitrile salt quickly went into solution (2-3 minutes), and the reaction mixture was allowed to stand for 15 minutes. Three times its volume of absolute ether was added, and a colorless oily liquid, which became completely crystalline in several minutes, rapidly separated. After a half-hour the residue was filtered by suction, washed three times with absolute ether, and dried in a vacuum dessicator. Yield 2.6 g (82.5% of theoretical). M.p. 244-247° (with decomposition). It was soluble in water with the evolution of heat.

0.2031 g, 0.2120 g substance: 20.95 ml, 22.00 ml 0.1 N H_2SO_4 (Kjeldahl). 0.2250 g, 0.2350 g substance: 23.47 ml, 24.60 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 14.44, 14.52; Cl 37.03, 37.16. $C_5H_{14}ON_2Cl_2$. Calculated %: N 14.81; Cl 37.62.

V. N-Phenylglycineiminomethyl ether

N-Phenylglycinenitrile hydrochloride [12]. We prepared N-phenylglycinenitrile from 32 ml formalin (specific gravity 1.078), 37 ml aniline, and 40 g potassium cyanide. Yield 41 g, light yellow crystals with m.p. 44-45°. After recrystallization from ether we obtained almost colorless crystals, m.p. 47-48°.

The nitrile hydrochloride was prepared by dissolving the nitrile in ether and adding a saturated solution of hydrogen chloride in alcohol until reaction was acid to Congo red. The precipitate which separated was filtered by suction, washed with ether, and recrystallized from ethyl alcohol. Colorless crystals which decomposed without melting when heated to 200°.

N-Phenylglycineiminomethyl ether dihydrochloride. 50 ml absolute methyl alcohol which had been saturated cold with hydrogen chloride was added to 3 g finely crushed N-phenylglycinenitrile hydrochloride. The nitrile salt went into solution after about 3-5 minutes of agitation with cooling, and soon thereafter the imino-ether salt began to separate. The residue was filtered by suction after 1.5 hours, washed several times with absolute ether, and dried in a vacuum dessicator. Colorless crystals; m.p. 185-186°. Yield 3.0 g (71.5% of theoretical). The material was soluble in water, and poorly soluble in ethyl alcohol.

0.1952 g, 0.2004 g substance: 16.0 ml, 16.85 ml, 0.1 N. H_2SO_4 (Kjeldahl). 0.2002 g, 0.2246 g substance: 16.85 ml, 18.70 ml 0.1 N. $AgNO_3$ (Volhard). Found %: N 11.91, 11.77; Cl 29.88, 29.56. $C_9H_{14}ON_2Cl_2$. Calculated %: N 11.82; Cl 29.95.

VI. Attempted preparation of α-phenylglycineiminomethyl ether.

α-Phenylglycinenitrile hydrochloride. We prepared this from 10 g benzaldehyde, 10 g potassium cyanide, and 5 g ammonium chloride, following N.D. Zelinsky and G. L. Stadnikov [13]. Yield 9.8 g, slightly yellowish crystals. The dried and crushed substance was treated several times with chloroform and then washed several times with ether; this gave a product which was free of color. M.p. 175-176°.

Attempted preparation of α-phenylglycineiminomethyl ether dihydrochloride. 60 ml absolute methyl alcohol which had been saturated cold with hydrogen chloride was added to 3 g α-phenylglycinenitrile hydrochloride. On continued agitation with cooling, the nitrile salt finished going into solution in 6-8 minutes. After cooling for 10 minutes in ice water, we added 3-4 times its volume of absolute ether; if the temperature of the reaction mixture was sufficiently low, precipitation did not noticeably begin at this time, and the mixture was let stand overnight. The finely crystalline precipitate which separated during this time was filtered by suction, washed with ether, and dried in a vacuum dessicator. Yield 3.2 g. M.p. 272-273°. Poorly soluble in alcohol; insoluble in ether and chloroform. An aqueous solution of the substance developed a violet color with copper salts and alkali.

Recrystallization from water gave colorless crystals, with m.p. 280-281° (with decomposition), which retained the property of the un-recrystallized material to give a violet-colored copper complex.

3.295 mg, 3.108 mg substance: 6.267 mg, 5.898 mg CO_2; 1.645 mg H_2O. 4.195 mg, 2.867 mg substance: 0.549 ml, 0.375 ml N_2 (22.50°, 745 mm). Found %: C 51.90, 51.79; H 6.06, 5.92; N 14.85, 14.81. $C_8H_{11}ON_2Cl$. Calculated %: C 51.47; H 5.89; N 15.01.

From this it appears that the reaction product was not α-phenylglycineiminomethyl ether, dihydrochloride but rather α-phenylglycineamide hydrochloride.

VII. Alanineiminomethyl ether.

Alaninenitrile hydrochloride [14]. We prepared alaninenitrile from 26.6 g ammonium chloride, 10 g acetaldehyde, and 29.5 g potassium cyanide. Hydrogen chloride was passed through an ether solution of the nitrile until the solution was acid to Congo red. The yellowish-white precipitate which separated was filtered by suction, washed with ether, and dried in a vacuum dessicator. Yield 23 g. M.p. 126-128°. (According to the literature the m.p. is 115-117° [15] and 132-133° [16]).

As a consequence of the difficulty of purifying the substance, it was used in the next stage without further treatment.

Alanineiminomethyl ether dihydrochloride. 35 ml absolute methyl alcohol which had been saturated cold with hydrogen chloride was added to 2 g alaninenitrile hydrochloride. The nitrile salt dissolved in intermittent agitation while cooling in ice-water, and after a half-hour absolute ether was added to the solution until turbidity was not cleared up by shaking; the mixture was then let stand for one and one-half hours while cooling in ice water. The precipitate which separated was filtered by suction, washed with ether, and dried in a vacuum dessicator. Yield 2 g (60.5% of theoretical), slightly yellowish hygroscopic material, liberates heat when dissolved in water. The material was poorly soluble in ethyl alcohol, somewhat more soluble in methyl alcohol, and insoluble in ether and chloroform.

0.2132 g, 0.1976 g substance: 23.6 ml, 22.4 ml 0.1 N H_2SO_4 (Kjeldahl). 0.1938 g, 0.1640 g substance: 21.40 ml, 18.00 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 15.50, 15.87; Cl 39.20, 38.96. $C_4H_{12}ON_2Cl_2$. Calculated %: N 16.00; Cl 40.6.

The analytical results were somewhat low and the material was somewhat colored, no doubt because of incompletely pure initial nitrile; however, there is no doubt that the material was the desired imino-ether.

VIII. β-Dimethylaminopropioniminomethyl ether.

35 ml absolute methyl alcohol which had been saturated when cold with dry hydrogen chloride was added to 2 g β-dimethylaminopropionitrile hydrochloride (m.p. 203-204°). The starting nitrile salt dissolved in 2-3 minutes of shaking, while cooled in ice-water. After 10 minutes the reaction mix was diluted with one and one-half times its volume of absolute ether. The finely crystalline white precipitate (1.5 g) which separated at once appeared to be unchanged aminonitrile salt. On extension of the reaction time to one-half hour, addition of one and one-half volumes of absolute ether gave a transparent solution on shaking from which colorless fine prisms separated gradually on standing when cold. After 2 hours the residue was filtered by suction, washed with ether, and dried in a vacuum dessicator. Yield 2.3 g (76 % of theoretical). On heating the material effervesced and decomposed at about 100°. Readily soluble in water, less soluble in methyl alcohol.

0.2012 g, 0.2238 g substance: 20.1 ml, 22.15 ml 0.1 N H_2SO_4 (Kjeldahl). 0.1904 g, 0.2319 g substance: 18.75 ml, 23.0 ml 0.1 N $AgNO_3$ (Volhard). Found %: N 13.96, 13.86; Cl 34.95, 35.20. $C_6H_{16}ON_2Cl_2$. Calculated %: N 13.80; Cl 34.97.

IX. m-Aminobenziminomethyl ether.

m-Nitrobenzonitrile [17]. This was prepared from 25 g *m*-nitroaniline, 12.5 g sodium nitrite, 45 g copper sulfate, and 51 g potassium cyanide. Light yellow crystals with m.p. 113-114° (m.p. 117° [17]). Yield 8 g. Because of large losses in purification, the prepared substance was used in the next stage without further treatment.

m-Aminobenzonitrile [17]. We prepared this from 8 g *m*-nitrobenzonitrile by reduction with 48 g stannous chloride. Yield 45 g; slightly yellowish crystals with m.p. 49° (m.p. 53-53.5° [17].

The nitrile was purified via its hydrochloride. For this, we gradually added, with cooling, ether, which had been saturated with hydrogen chloride, to an ether-alcohol solution of the substance. The white precipitate of m-aminobenzonitrile hydrochloride was filtered by suction, washed with ether, and then twice recrystallized from methyl alcohol. Colorless crystals, m.p. 209-210°.

m-Aminobenziminomethyl ether dihydrochloride. 15 ml absolute methyl alcohol, saturated when cold with hydrogen chloride, was added to 0.5 g *m*-aminobenzonitrile hydrochloride. The reaction mixture was allowed to stand at room temperature with periodic shaking. Solution of the nitrile salt was complete in about a half-hour, and in a short while the solution then began to deposit a fibrous, cotton-like, colorless precipitate. The mixture was cooled in ice for 1.5 hours, the residue was then filtered by suction, washed several times with ether, and dried in a vacuum dessicator. Yield 0.45 g (62% of theoretical). M.p. 238-240° (with decomposition). Using ether, we were able to separate an additional quantity of material from the same mother liquor.

Light colorless thread-like crysals which were difficultly soluble in methyl alcohol and readily soluble in water without displaying significant thermal effect.

0.1486 g substance: 13.1 ml 0.1 N H_2SO_4 (Kheldahl). 0.1534 g substance: 13.8 ml 0.1 N $AgNO_3$. (Volhard). Found %: N 12.35; Cl 31.93. $C_8H_{12}ON_2Cl_2$. Calculated %: N 12.55; Cl 31.83.

SUMMARY

1. A method was developed for synthesis of imino-ethers of α-amino acids and its applicability for synthesis of aromatic and β-series imino-ethers demonstrated.

2. It was shown that formation of these compounds takes place quickly and completely, and that the imino-ether formed is relatively stable, in presence of alcohol saturated with hydrogen chloride. This enabled separation of

reaction products in a sufficiently pure form without resorting to additional purification. The effect of the amino group location on the velocity of formation of imino-ethers was noted for α- and β-amino acids.

3. The following group of new imino-ethers of α-amino acids was prepared: aminoacetiminomethyl ether, dimethylaminoacetiminomethyl ether, dimethylaminoacetiminoethyl ether, aminoisobutyroiminomethyl ether, alanineiminomethyl ether, and α-phenylglycineiminomethyl ether.

A representative aromatic ether (m-aminobenziminomethyl ether) and a β-type ether (dimethylaminopropiominomethyl ether) were analogously prepared.

Consequently, the proposed method may be regarded as a sufficiently general method for synthesis of amino acid imino-ethers.

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AMIDINES OF AMINO ACIDS. II

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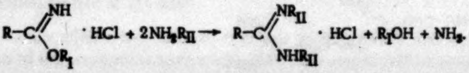
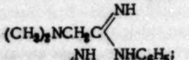
The wide variety of applications and valuable properties of amidines – compounds having the general formula $R{-}C\langle{}^{NR_I}_{NR_{II}R_{III}}$ (R, R_I, R_{II}, R_{III} = H or organic radicals) – fully justifies the considerable interest chemists have shown in them, which has been reflected by the extensive literature, chiefly in patents, associated with these compounds. Among the many different compounds of this class, amidines of amino acids (where R is an aminoalkyl group) have been described very slightly. But precisely these compounds (mainly amidines of α-amino acids), apart from their possible practical utilization, are of fundamental interest from the point of view of the structure of albumin, as introduced by N.D. Zelinsky and N.I. Gavrilov [1]; consequently, successful synthesis of these compounds is of unconditional interest. For preparation of these compounds we selected a method based on reacting imino-ether salts with amines, which would lead, as a rule, to di-substituted compounds.



$$R{-}C\langle{}^{NH}_{OR_I}\cdot HCl + 2NH_2R_{II} \rightarrow R{-}C\langle{}^{NR_{II}}_{NHR_{II}}\cdot HCl + R_IOH + NH_3.$$

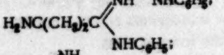
The hydrochlorides of the amino acid imino-ethers necessary were prepared by a previously described method [2]. We used the ordinary procedure, described in the literature, for preparation of the amidines: a mixture of imino-ether salt and amine in solvent (we used absolute ether) was allowed to stand at room temperature for 1-3 days, and the amidine hydrochloride which formed was then separated by a suitable procedure. Since it might be expected that imino-ethers of amino acids with a primary amino group would react in a complex way with aliphatic amines, caused by participation of the amino group of the aminoimino-ether, and because of the unavoidable interchange of hydrogen chloride between the amino groups of the imino-ether and the reacting amine, we used an amine with reduced basicity-aniline. In this way we prepared, from the corresponding imino-ether salts, the following amidines as dihydrochlorides:

N-phenyl-dimethylaminoacetamidine:



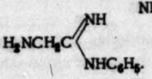
$(CH_3)_2NCH_2C\langle{}^{NH}_{NHC_6H_5}$;

N-phenyl-aminosiobutyramidine:



$H_2NC(CH_3)_2C\langle{}^{NH}_{NHC_6H_5}$;

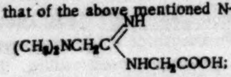
N-phenyl-aminoacetamidine:



$H_2NCH_2C\langle{}^{NH}_{NHC_6H_5}$.

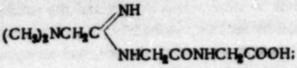
Using the property of dimethylaminoacetamidines to form dipricrates which crystallize well and are difficultly soluble in alcohol (this was used for separation of N-benzyl-dimethylaminoacetamidine in the pure form) we were able to simplify somewhat the method of preparation in some cases: a solution of amine picrate in methyl alcohol was added to the hydrochloride of the imino-ether mentioned; the solution quickly became homogeneous and then, after several minutes, the amidine salt began to separate. In this way we were able to prepare the dipicrates of the following compounds in addition to that of the above mentioned N-phenyl-dimethylaminoacetamidine:

N-glycyl-dimethylaminoacetamidine:



$(CH_3)_2NCH_2C\langle{}^{NH}_{NHCH_2COOH}$;

N-glycylglycyl-dimethylaminoacetamidine:



$(CH_3)_2NCH_2C\langle{}^{NH}_{NHCH_2CONHCH_2COOH}$;

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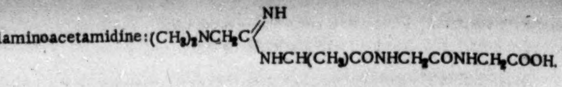
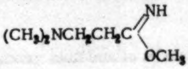
[*] Deceased

N-dl-alanylglycylglycyl-dimethylaminoacetamidine:



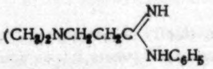
$$(CH_3)_2NCH_2C\begin{cases}NH\\NHCH(CH_3)CONHCH_2CONHCH_2COOH.\end{cases}$$

The last compound is of interest because it contains a combination of peptide and amidine linkages. As can be seen from the formulas given, all the above compounds are mono-substituted amidines. Attempts to prepare the corresponding disubstituted compound – N,N'-diphenyl-dimethylaminoacetamidine (in place of N-phenyl-dimethylaminoacetamidine) – by using excess aniline and increasing the length of reaction time, lead to formation of the mono-substituted compound without change. Performing the reaction in boiling absolute ether gave the same result. However, aminoimino-ether salts of the β-type – β-dimethylaminopropioiminomethyl ether



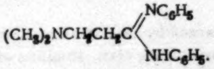
$$(CH_3)_2NCH_2CH_2C\begin{cases}NH\\OCH_3\end{cases}$$

– readily reacted with aniline to give, depending on the reagent ratio, both mono- and di-substituted amidines:



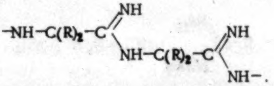
$$(CH_3)_2NCH_2CH_2C\begin{cases}NH\\NHC_6H_5\end{cases}$$

and



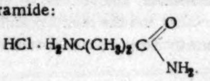
$$(CH_3)_2NCH_2CH_2C\begin{cases}NC_6H_5\\NHC_6H_5.\end{cases}$$

Imino-ethers of amino acids with primary amino groups (for example aminoacetiminomethyl ether and aminoisobutyroiminomethyl ether), have two functional groupings which can react with one another (the amino and the imino-ether groups) to form amidine linkages; this affords the possibility of using these compounds both as the imino-ether and the amino component of the reaction at the same time. In this way unusual amidine polycondensations may take place:



$$-NH-C(R)_2-C\begin{cases}NH\\NH-C(R)_2-C\begin{cases}NH\\NH-.\end{cases}\end{cases}$$

Cyclic compounds may also be formed in this manner. Because the amino acid imino-ethers prepared in our synthesis were separated as dihydrochlorides, it was necessary to remove one molecule of hydrogen chloride from the compound in order to make reactions of the above discussed type feasible; this was accomplished, based on the very different basicity of amino and imino-ether groups, by treating the imino-ether with pyridine. However, use of this reaction on the dihyrochloride of aminoisobutyroiminomethyl ether gave, instead of the desired product, the hydrochloride of aminoisobutyramide:



$$HCl\cdot H_2NC(CH_3)_2C\begin{cases}O\\NH_2.\end{cases}$$

The similar behavior of several α-substituted imino-ethers which give amides on separation of the free base from the imino-ether salt has been noted in the literature [3]. There are also references to the effect that alcoholysis of imino-ether salts, in which there are two or three substituents on the α-carbon atom, does not lead to orthoesters as is usual, but gives the corresponding amide, for the most part [4].

On treatment of aminoacetiminomethyl ether dihydrochloride with pyridine, we obtained a material whose properties differed both from the corresponding amide and from the initial imino-ether. We were able to conclude that the reaction had gone in the desired direction because of similarity of a number of properties between this compound and N-phenyl-aminoacetamidine (i.e., easy oxidizability in aqueous solution, and ability to give color reactions with certain metallic salts). However, because of the difficulty of purifying the substance prepared, we are not able to make firm conclusions on its structure, for the present.

EXPERIMENTAL

N-Phenyl-dimethylaminoacetamidine-dihydrochloride. 10 ml absolute ether was added to 1 g freshly prepared dimethylaminoacetiminomethyl ether dihydrochloride which was ground as finely as possible. A solution of 1 ml aniline in 5 ml absolute ether was then added gradually with cooling. The mixture was allowed to stand at room temperature for a day. From time to time it was shaken and the residue stirred up (with atmospheric moisture excluded). The residue was filtered by suction, washed twice with ether. Yield 1.25 g (96 % of theoretical). The substance was dissolved in a small amount of methyl alcohol, and an equal volume of ether added to the solution. On shaking, the initial turbidity disappeared, and then colorless glistening flakelets began to separate gradually from the transparent solution. After some time the residue was suction filtered, washed first with an alcohol-ether mixture and then with ether, and dried. Yield 1 g (76% of theoretical).

M.p. 226-227° (with decomp.). A second crystallization of the substance by the above described method gave m.p. 227-228° (with decomp.).

Glistening plates, readily soluble in water and methyl alcohol, less soluble in ethyl alcohol, and insoluble in benzene and ether.

0.1958 g substance: 22.88 ml 0.1 N H_2SO_4 (Kjeldahl). 0.2064 g substance: 24.48 ml 0.1 N. H_2SO_4. 0.2008 g substance: 16.2 ml 0.1 N $AgNO_3$ (Volhard). 0.1876 g substance: 15.05 ml 0.1 N. $AgNO_3$. Found %: N 16.36, 16.60; Cl 28.6, 28.55. $C_{10}H_{17}N_3Cl_2$. Calculated %: N 16.80; Cl 28.40.

The substance gave a bright blue color with copper salts in aqueous solution in presence of alkali.

N-Phenyl-aminoisobutyramidine-dihydrochloride. 7 ml absolute ether was added to 1.6 g freshly prepared aminoisobutyriminomethyl ether dihydrochloride, 2 ml dry aniline was then added with cooling. The reaction mixture was periodically shaken, and after a day the residue was suction filtered and washed with ether. After drying in a vacuum dessicator we obtained 2 g of material. The latter was treated with a small quantity of ethyl alcohol; most of the material remained undissolved. The mother liquor was removed by suction and discarded (ether separated from the mother liquor a colorless crystalline substance which gave a violet color when treated in aqueous solution with a copper salt and alkali – indicating presence of aminoisobutyramide) and the residue washed with ethyl alcohol, dissolved in methyl alcohol, filtered, and an equal volume of absolute ethyl alcohol added to the solution. In several hours, well-formed crystals separated; these were filtered by suction, washed with ethyl alcohol and ether, and dried in a vacuum dessicator. Yield 1 g. M.p. 246-247°. A mixed melting point test with aminoisobutyramide hydrochloride melted at 230-234°.

The material was readily soluble in water, less soluble in methyl alcohol, and poorly soluble in ethyl alcohol. The aqueous solution of the preparation gave a blue color with copper salts in presence of alkali.

0.1832 g substance: 21.5 ml 0.1 N H_2SO_4. 0.1563 g substance: 18.75 ml 0.1 N H_2SO_4: 0.2100 g substance: 16.9 ml 0.1 N $AgNO_3$. 0.1924 g substance: 15.6 ml 0.1 N $AgNO_3$. Found %: N 16.44, 16.8; Cl 28.56, 28.78. $C_{10}H_{17}N_3Cl_2$. Calculated %: N 16.80; Cl 28.40.

N-Phenyl-aminoacetamidine [(N-phenyl-glycineamidine)-dihydrochloride]. To 1.4 g freshly prepared aminoacetiminomethyl ether dihydrochloride, carefully triturated in 10 ml absolute ether, we added with cooling a solution of 1.5 ml dry aniline in 8 ml ether and allowed the reaction mixture to stand with occasional shaking. A noticeable re-formation of the precipitate took place fairly quickly. After 10 hours the residue was filtered by suction (protected from atmospheric moisture), washed with ether, and dried in a vacuum dessicator. Yield 1.9 g (98% of theoretical). Colorless substance, fairly readily soluble in methyl alcohol. From the solution, ether separated a yellowish oil, which solidified on stirring with ether. After vacuum drying at 60° we obtained an amorphous brownish-white material with a 150-155° melting point range during which it effervesced vigorously and decomposed.

0.1473 g substance: 20.13 ml 0.1 N H_2SO_4. 0.1542 g substance: 20.9 ml 0.1 N H_2SO_4. 0.1038 g substance: 9.35 ml 0.1 N. $AgNO_3$. Found %: N 19.13, 18.98; Cl 31.97. $C_8H_{13}N_3Cl_2$. Calculated %: N 18.91; Cl 31.99.

The preparation was readily soluble in water and in methyl alcohol. The solutions quickly became colored on standing, becoming more intense with the passage of time, and a dark precipitate began to separate. The rate of separation of precipitate could be increased by adding sufficient dilute alkali to separate the amidine as a free base. Addition of hydrogen peroxide or passage of air through the solution very considerably accelerated this process.

Aqueous $FeCl_3$ solution gave a blood-red colored solution with N-phenyl-glycine-amidine dihydrochloride, which developed a dirty brown color on standing.

N-Benzyl-dimethylaminoacetamidine-dipicrate. A solution of 2.5 g benzylamide in a small quantity of ether was added with cooling to 1.3 g dimethylaminoacetiminomethyl ether dihydrochloride in 15 ml absolute ether.

After 3 hours the precipitate was suction filtered and washed well with ether. Weight 2.5 g. The material was dissolved in absolute ethyl alcohol and filtered; to the filtrate we added about one third of its volume of ether. The precipitate which separated was filtered by suction and washed with ether. Weight 0.4 g. M.p. 243-244°. In a mixed melting point test with benzylamine hydrochloride, no depression was obtained.

We then added twice its volume of ether to the filtrate. This precipitate was washed with ether and dried in a vaccum dessicator. Weight 1.4 g. M.p. 155-158°. An abundant yellow precipitate, melting at 219-220°, was obtained on addition of a solution of picric acid in methyl alcohol. When a considerable quantity of ether was added to the previous filtrate an additional 0.4 g of material melting at 156-160° was separated; this substance, like the previous fraction, gave a compound melting at 219-220° with picric acid.

The total yield of N-benzyl-dimethylaminoacetamidine dipicrate was 3.8 g (83% of theoretical). The material was insoluble in water and ether and slightly soluble in methyl and ethyl alcohol.

2.370 mg substance: 0.403 ml N_2 (22°, 795 mm). 2.240 mg substance: 0.386 ml N_2 (22.5°, 796 mm). Found %: N 19.29, 19.53. $C_{23}H_{23}O_{14}N_9$. Calculated %: N 19.41.

N-Phenyl-dimethylaminoacetamidine-dipicrate. We dissolved 1.2 g picric acid in 30 ml absolute methyl alcohol and added 0.7 ml dry aniline. The alcoholic solution was quickly added to 0.6 g freshly prepared dimethylaminoacetiminomethyl ether dihydrochloride. The imino-ether salt rapidly dissolved, and in 3-5 minutes a yellow crystalline precipitate of amidine dipicrate began to separate. The precipitate was filtered by suction after 2 hours, and washed twice with methyl alcohol and then with ether. After drying in a vacuum dessicator, the weight of substance was 0.7 g (21% of theoretical). M.p. 217-218° (with decomp.). The substance was insoluble in ether, very slightly soluble in water, and slightly soluble in cold methyl alcohol. In attempts to recrystallize it from hot methyl alcohol, partial decomposition of the substance was observed.

3.938 mg substance: 1.261 mg H_2O. 6.127 mg CO_2. 4.220 mg substance: 1.325 mg H_2O, 6.443 mg CO_2. 2.636 mg substance: 0.449 ml N_2 (16°, 748 mm). 2.206 mg substance: 0.375 ml N_2 (16.5°, 748 mm). Found %: C 41.92, 41.67; H 3.54, 3.51; N 19.80, 19.73. $C_{22}H_{21}O_{14}N_9$. Calculated %: C 41.58; H 3.31; N 19.85.

By treating a solution of N-phenyl-dimethylaminoacetamidine dihyrochloride in methyl alcohol with an alcoholic solution of picric acid, a yellow precipitate rapidly began to separate; this, after washing with alcohol and ether, and drying had m.p. 217-218°. It did not depress the melting point of the N-phenyl-dimethylaminoacetamidine dipicrate prepared above.

N-Glycyl-dimethylaminoacetamidine-dipicrate. We dissolved 0.4 g glycine in 20 ml absolute methyl alcohol which contained 1.5 g picric acid. 0.5 g freshly prepared dimethylaminoacetiminomethyl ether dihydrochloride was added to the solution of glycine picrate; it dissolved very quickly. The transparent solution thus prepared soon began to deposit yellow crystals. The precipitate which formed in an hour was filtered by suction, washed with methyl alcohol, and dried in a vacuum dessicator. Yield 0.6 g (32% of theoretical). M.p. 143-144° (with decomp.). The substance was poorly soluble in most organic solvents.

5.570 mg substance: 0.963 ml N_2 (18°, 755 mm). 5.300 mg substance: 0.920 ml N_2 (18°, 755 mm). Found %: N 20.15, 20.18. $C_{18}H_{19}O_{16}N_9$. Calculated %: N 20.43.

N-dl-Alanylglycylglycyl-dimethylaminoacetamidine-dipicrate. We prepared this, by the procedure of the preceding experiment, from a solution of 0.15 g dl-alanylglycylglycine and 0.5 g picric acid in 10 ml absolute methyl alcohol and 0.5 g dimethylaminoacetiminomethyl ether salt. Yield 0.13 g (20% of theoretical). It had an unsharp melting point of about 120°. It was somewhat soluble in methyl alcohol.

3.685 mg substance: 0.689 ml N_2 (26°, 743 mm). 4.530 mg substance: 0.849 ml N_2 (27°, 743 ml). Found %: N 20.73, 20.90. $C_{23}H_{27}O_{18}N_{11}$. Calculated %: N 20.68.

N-Phenyl-β-dimethylaminopropylamidine-dihydrochloride. To 1 g freshly prepared β-dimethylaminopropyliminomethyl ether dihydrochloride, suspended in 10 ml absolute ether, was added a solution of 1 ml dry aniline in a small quantity of ether and the mixture allowed to stand for three days with occasional shaking. The precipitate which formed in this period was filtered by suction and washed several times with ether. Yield 1.4 g. The substance was dissolved in hot absolute methyl alcohol, and a small quantity of absolute ether added to the solution after cooling. After a short while it was filtered by suction. 0.1 g ammonium chloride was on the filter. Further addition of dry ether to the filtrate caused the separation of a finely-crystalline material, which was suction filtered and washed with ether. Weight 1 g. After two recrystallizations from absolute ethyl alcohol, we obtained colorless crystals with m.p. 176-177.5°. The material was readily soluble in water and in methyl alcohol and was difficultly soluble in ethyl alcohol.

0.1290 g substance: 14.6 ml 0.1 N. H_2SO_4 (Kjeldahl). 0.1454 g substance: 16.75 ml 0.1 N H_2SO_4
0.1294 g substance: 9.85 ml 0.1 N. $AgNO_3$ (Volhard). Found %: N 15.85, 16.12; Cl 27.10.
$C_{11}H_{19}N_3Cl_2$. Calculated %: N 15.90; Cl 26.90.

N,N'-Diphenyl-β-dimethylaminopropylamidine-dihyrochloride. A solution of 4 ml aniline in a small quantity of dry ether was added to 2.2 g freshly prepared β-dimethyl-aminopropyliminomethyl ether dihydrochloride triturated in 10 ml absolute ether. The mixture was let stand for two days with occasional shaking. At the end of this time a semi-solid material had settled to the bottom of the reaction vessel. We added double the volume of dry ether (for more complete separation of the substance which, because of high aniline concentration, was partially in solution), and, after a short while, carefully decanted the reaction liquid from the residue. The residue was ground up several times with ether for separation of unreacted amine and then dissolved in a small quantity of absolute ethyl alcohol. Undissolved ammonium chloride was removed by filtration, and an ether solution of hydrogen chloride added to the filtrate until slightly acid. In order to separate the material more completely , we added still more ether, and then, when precipitation was complete, filtered the residue, washed it with ether, and dried it in a vacuum dessicator. Yield 3.5 g. It was twice recrystallized from absolute ethyl alcohol, yielding a colorless crystalline material which was readily soluble in water and methyl alcohol and somewhat less soluble in ethyl alcohol. M.p. 193-194°.

0.1292 g substance: 11.6 ml 0.1 N. H_2SO_4 (Kjeldahl). 0.2014 g substance: 18.25 ml 0.1 N H_2SO_4.
0.2048 g substance: 12.25 ml 0.1N $AgNO_3$ (Volhard). Found %: N 12.56, 12.68. Cl 21.23.
$C_{17}H_{23}N_3Cl_2$. Calculated %: N 12.35; Cl 20.89.

Picrate treatment of aminoisobutyroiminomethyl ether dihyrochloride. 15 ml dry pyridine was added with cooling to 3 g aminoisobutyroiminomethyl ether dihydrochloride. The imino-ether salt dissolved amost completely in 15-20 minutes with periodic agitation and a colorless resinous precipitate began to form. After an hour the pyridine was poured off and the residue washed and triturated several times with chloroform and then with ether. The residue was dissolved in methyl alcohol and an excess of ether then added to the solution. A crystalline precipitate separated, which we removed by filtration and washed with ether. After recrystallization from methyl alcohol its m.p. was 264-266° (with decomp.). The material was readily soluble in water and less soluble in methyl and ethyl alcohol. In aqueous solution it formed a violet complex with copper salts and alkali.

3.52 mg substance: 4.485 mg CO_2; 2.559 mg H_2O. 1.955 mg substance: 0.350 ml N_2 (15.5°, 724 mm).
Found %: C 34.77; H 8.13; N 20.18. $C_4H_{11}ON_2Cl$. Calculated %: C 34.78; H 7.95, N 20.2.

The prepared material thus appears to have been aminoisobutyramide hydrochloride. The same material is obtained by treatment of the imino-ether salt with the theoretical quantity of pyridine in absolute methyl alcohol.

SUMMARY

1. We prepared a group of N-substituted amino acid amidines, as follows: N-phenylaminoacetamidine, N-phenyl-dimethyl-aminoacetamidine, N-glycyldimethylaminoacetamidine, N-glycylglycyl-dimethylamino-acetamidine, N-dl-alanylglycylglycyl-dimethylaminoacetamidine. The picrates formed readily in most cases, immediately following mixing the dimethylaminoacetiminomethyl ether salt with the picrate of the corresponding amine in alcoholic solution.

2. We noted the tendency of α-amino acid imino-ethers to yield only the mono-substituted amidine, whereas β-dimethylaminopropyliminomethyl ether on reaction with aniline under analogous conditions readily gave, depending on the reagent ratio, either the mono or the di-substituted amidine.

3. Treatment of aminoisobutyroiminomethyl ether dihydrochloride with pyridine gave aminoisobutyramide hydrochloride. Similar treatment of aminoacetiminomethyl ether dihydrochloride produced a material of undetermined structure.

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Chair of Organic Chemistry

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* See Consultants Bureau translation page 2077.

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SUMMARY

1. We prepared a series of [illegible]

2. We noted [illegible]

3. Treatment of [illegible]

LITERATURE CITED

[1] [illegible]

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Moscow State University [illegible]

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* See Consultants Bureau translation page [illegible]

THE SULFONATION REACTION

XXV. SOME PROPERTIES OF NAPHTHALENE TRISULFONYLCHLORIDES

A. A. Spryskov

Of the three naphthalene trisulfonic acids which can be prepared by direct sulfonation, the 1,3,6-trisulfonic has considerable technical value for preparation of H-acid while the 1,3,5-acid has some importance. This, of course, does not mean that the 1,3,7-acid does not have any application. One of the reasons for the insufficiently wide utilization of all the naphthalene trisulfonic acids appears to be the lack of a practical method for separation of the sulfonation mixture into separate isomers because the properties of the trisulfonic acids and their derivatives have been very incompletely studied. Data on solubility of the trisulfonylchlorides in several solvents as well as data on thermal analysis of their mixtures may be of considerable help in investigating mixed naphthalene trisulfonic acids.

We give below results obtained for the solubility in benzene of 1,3,5-, 1,3,6- and 1,3,7-naphthalenetrisulfonylchlorides and the thermal analysis of binary mixtures of the trisulfonylchlorides.

Solubility of Naphthalene-trisulfonylchlorides in benzene (grams of substance per 100 g solvent)

1,3,5-trichloride		1,3,6-trichloride		1,3,7-trichloride	
at 20°	at 30°	at 20°	at 30°	at 20°	at 30°
14.55	17.50	10.64	14.80	0.86	1.45
14.65	17.54	10.63	14.85	0.86	1.46
14.63		10.87		0.83	1.48

Results of determination of benzene solubility of the trisulfonylchlorides at 20° and 30° are given in the table. The experiments showed that the 1,3,5- isomer was the most readily soluble and that the 1,3,6-isomer was somewhat less soluble. The solubility of the 1,3,7-isomer was substantially different from that of the first two. This difference in solubility allows separation of the 1,3,7-chloride from the 1,3,5- and 1,3,6-chlorides by treatment of the mixture with benzene.

In complete sulfonation of naphthalene a mixture of only two acids is obtained: 1,3,6-naphthalene-trisulfonic acid and 1,3,5,7-naphthalene-tetrasulfonic acid. This prompted us also to determine the benzene solubility of 1,3,5,7-naphthalene-tetrasulfonylchloride at 20°. The test showed that the tetrachloride was very slightly soluble in benzene. Thus, we found (from the residue after evaporating benzene from a saturated chloride solution) that 100 g benzene dissolved 0.02 g tetrachloride (average of 0.021, 0.023, 0.030). Benzene treatment would thus readily and completely separate the tetrachloride from the 1,3,6-trichloride in products obtained by exhaustive sulfonation.

Results of thermal analysis of binary mixtures of 1,3,5-, 1,3,6- and 1,3,7-trisulfonylchlorides are given in Figures 1, 2, and 3. The results show that the trisulfonylchlorides do not form chemical compounds with each other. The 1,3,5- and 1,3,6-chloride system has a eutectic point at 127°, composition of which corresponds to 74% of the 1,3,5-isomer.

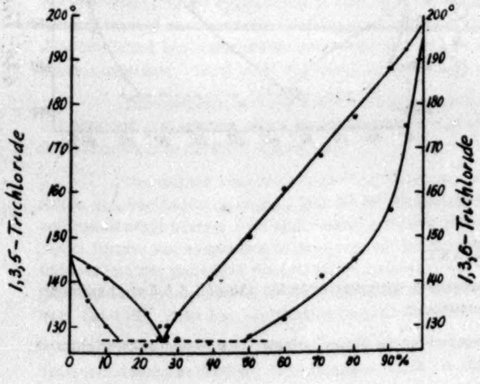

Figure 1.

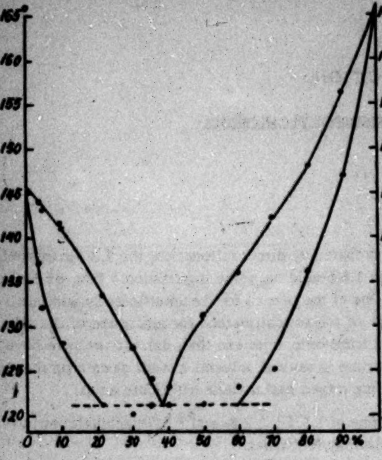

Figure 2.

The 1,3,5- and 1,3,7-isomer system has a 121° eutectic point, corresponding composition 61% 1,3,5-isomer; and the 1,3,6-, 1,3,7- isomer system has a eutectic point of 144° with a corresponding composition of 35% 1,3,6-isomer.

It was shown in one of our papers [1] that 1,7-naphthalene-disulfonylchloride gave, by reaction with chlorsulfonic acid, a mixture of 1,3,5- and 1,3,7-trisulfonylchlorides which melted at 135-144°. Based on these equilibrium thermal diagrams, we may conclude that sulfonation of 1,7-disulfonylchloride yields about 4% 1,3,7- and 96% 1,3,5-trisulfonylchloride.

In sulfonation of 1,3-naphthalene disulfonylchloride we obtained a mixture of all three trisulfonylchlorides, inasmuch as the sulfonation product melted at a temperature below the eutectic point of any of the binary mixtures.

EXPERIMENTAL

For the tests we used 1,3,5-naphthalene-trisulfonylchloride with m.p. 146°, 1,3,6-chloride with m.p. 198°, and 1,3,7- chloride with m.p. 165.5°, and benzene with a 5° solidification temperature.

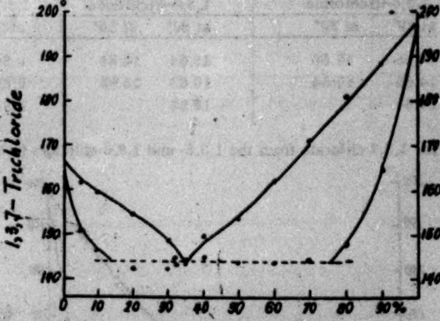

Figure 3.

Solubility determinations were made in a Pavlevsky apparatus [2], supplemented by a stirrer in the saturated solution container. The entire apparatus was mounted in a thermostat, the temperature of which was held with 0.1° of the values given in the table. Each run lasted 1.5 to 7 hours, with stirring.

The data for the thermal equilibrium diagrams were obtained in the following manner. The mixture of isomers was dissolved in benzene and the solvent evaporated. The residue was placed in a capillary and heated in an apparatus for melting point determination. The temperatures at which the first trace of liquid appeared and at which the last trace of crystals disappeared were observed. Heating took place sufficiently slowly that the temperature rose 1° in about 5 minutes, and the determination was repeated 3 or more times.

P. T. Pestov collaborated in this work.

SUMMARY

1. The solubility of 1,3,5-, 1,3,6-, and 1,3,7-naphthalene-trisulfonylchloride and of 1,3,5,7-naphthalene-tetrasulfonylchloride in benzene at 20° and 30° has been determined.

2. Thermal equilibrium diagrams have been prepared for the binary systems: 1,3,5- and 1,3,6-trichloride, 1,3,5- and 1,3,7-trichloride, and 1,3,6- and 1,3,7-trichloride.

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* See Consultants Bureau translation page 727.

3-ETHYLIMIDOSULFAMIDE AND ETHYLSULFAMIDE

A. V. Kirsanov and Yu. M. Zolotov

3-Ethylimidosulfamide was prepared with a 20.4% of theoretical yield by action of ethyl iodide on the silver salt of imidosulfamide. The very same ethylimidosulfamide was also prepared by reaction of diazoethane on free imidosulfamide with a yield which was 86.3% of the theoretical quantity. The formation of ethylimidosulfamide by this procedure shows, as does neutrality of its freshly prepared aqueous solution, that a hydrogen atom of the ethyl group is replaced by a middle nitrogen atom.

Thus, as does 3-methylimidosulfamide [1], 3-ethylimidosulfamide readily hydrolyzes completely with formation of sulfamic acid and ethylsulfamide.

EXPERIMENTAL

Ethylation of silver salt of imidosulfamide by ethyl iodide. Preliminary experiments showed that when a mixture of imidosulfamide silver salt stands at room temperature with excess ethyl iodide, almost exactly one molecule of ethyl iodide enters the reaction, although only 20.4% ethylimidosulfamide is thus formed. The rest of the ethyl iodide is used up, evidently by formation of polyethylated imidosulfamide from the reaction products. Consequently 39.9% of the imidosulfamide reacted with 79.8% of the ethyl iodide. It therefore follows that the polyethylated products are mainly diethylimidosulfamide. Actually, the yield of noncrystalline oily reaction product is in good agreement with these calculations. One of these experiments is described.

A mixture of 0.01 mole crushed anhydrous silver salt of imidosulfamide (2.82 g) and 3.0 ml ethyl idodide was allowed to stand for four days at room temperature in the dark. During this time the colorless silver salt of imidosulfamide was converted into light green silver iodide. Excess ethyl iodide was vaporized under vacuum at 40°. The reaction mixture weighed 4.36 g after this; consequently 1.54 g ethyl iodide reacted, i.e., 98.7% of the theoretical quantity. The dry mass was extracted twice by (125 ml) boiling benzene. From the first portion, 0.31 g 3-ethylimidosulfamide crystallized on cooling as snow-white, fine, matted needles. The product was filtered by suction and washed with benzene. Nothing separated from the second portion. The mother liquor and second portion were combined and concentrated on a water bath to a 25 ml volume. After a day, an additional 0.10 g of matted needles separated. Total yield of 3-ethylimidosulfamide was 0.41 g, i.e., 20.4% of the theoretical quantity.

The mother liquor was evaporated to dryness at 60° under vacuum. 0.82 g of an oily noncrystalline product was obtained as a residue. If we regard this material as mainly composed of diethylimidosulfamides, the yield of this corresponds to 35.4% of theoretical.

The residue after extraction of ethylated products by boiling benzene appeared to be a mixture of silver iodide and free imidosulfamide. In order to separate the latter mixture, we extracted it four times with 15.0 ml portions of ethyl acetate. We added some activated carbon to the turbid extract; after filtration the colorless, transparent filtrate was evaporated to dryness at 40° under vacuum. In order to remove the small quantity of ethylated imidosulfamides present in the crystalline residue, it was washed twice with 50 ml portions of boiling benzene and then dried under vacuum. The yield of free imidosulfamide was 0.69 g, i.e., 39.7% of the theoretical quantity; m.p. 154-158°. After recrystallization from acetone with benzene it gave fine needles, m.p. 163-165°.

Thus, overall reaction balance is: free imidosulfamide 39.7%, 3-ethylimidosulfamide 20.4%, oily products (considered as diethylimidosulfamides) 35.4%. Sum, 95.5% of theoretical. This agreement confirms the assumption that the oily product mainly consists of diethylimidosulfamides.

3-Ethylimidosulfamide was a colorless crystalline material, readily soluble in water, alcohol, acetone, ether, and ethyl acetate; it was very difficulty soluble in cold benzene – somewhat better in boiling benzene. Small quantities of 3-ethylimidosulfamide can be conveniently crystallized from benzene, larger quantities – from a mixture of ether and benzene. When recrystallized from benzene, 3-ethylimidosulfamide gave fine matted needles. When heated in a capillary, 3-ethylimidosulfamide melted without decomposition at 113-115°, i.e., almost the same as 3-methylimidosulfamide (113-114°).

A freshly prepared aqueous solution of 3-ethylimidosulfamide was neutral to Congo red and had a weak bitterish taste; however, even in a few minutes at room temperature the reaction to Congo red became acid and it developed an intensely acid taste, which indicates how quickly hydrolysis occurred.

0.0414 g substance: 0.0178 g CO_2; 0.0162 g H_2O. 0.0608 g substance. 0.0263 g CO_2; 0.0250 g H_2O. Found %: C 11.73, 11.80; H 4.36, 4.60. $C_2H_9O_4N_3S_2$. Calculated %: C 11.83; H 4.46.

Ethylation of free imidosulfamide with diazoethane. To a mixture of 0.02 mole crushed imidosulfamide (3.5 g) in 75 ml absolute ether at a temperature of about 10°, we added in small portions while vigorously stirring by hand, about 0.02 mole diazoethane as an approximately 0.2 N ether solution. After each addition the mixture began to turn yellow, and then decolorized with liberation of nitrogen. The imidosulfamide gradually went into solution. We stopped adding the diazoethane solution when the yellow color lasted for more than one minute.

0.5 g dry activated carbon was added to the turbid ether solution, and filtered. The entire colorless transparent solution was concentrated on a water bath to a volume of about 40 ml during which it began to crystallize. 200 ml absolute benzene was added to the warm solution, while stirring smoothly, and it was allowed to crystallize for 3-4 hours.

The precipitated 3-ethylimidosulfamide was filtered by suction, washed with benzene, and dried in a vacuum dessicator. Yield 2.63 g, m.p. 108-110°. The mother liquor was evaporated to a 50 ml volume, and the crystals which separated suction filtered and washed with benzene; yield 0.39 g, m.p. 111-113°. Total yield 3.02 g, i.e., 86.3% of the theoretical quantity.

For purification, the 3-ethylimidosulfamide was either dissolved in ether and precipitated by addition of five volumes of benzene, or it was recrystallized from a large volume of boiling benzene. Pure 3-ethylimidosulfamide melted at 113-115° (uncorr.) without decomposition and did not depress the melting point of 3-ethylimidosulfamide prepared from imidosulfamide silver salt and ethyl iodide.

Saponification of 3-ethylimidosulfamide. Preparation of ethylsulfamide. 2.63 g 3-ethylimidosulfamide was added to 10.0 ml water; the solution was quickly brought to a boil, cooled, and evaporated to dryness under vacuum on a water bath heated to 25°. The dry residue was extracted with acetone and the acetone solution evaporated to dryness under vacuum. The residue was ethylsulfamide in the form of a colorless oil, which when cooled and vigorously rubbed with a glass rod began to crystallize. Yield of ethylsulfamide was 1.31 g, i.e., 81.4% of the theoretical quantity. For purification, the product was extracted by boiling benzene. Combined benzene solutions were concentrated under vacuum to 25 ml, and this solution allowed to crystallize at 10°. Within a day, fine needles separated which were similar to glass wool; they were suction filtered, washed with benzene, and dried under vacuum. Yield 0.85 g, m.p. 30-32° (uncorr.). For further purification, the product was dissolved in 1.5 ml acetone and 15 ml benzene added to the solution. The crystals which separated were washed with benzene and dried. Yield 0.63 g, m.p. 33-35°. Melting point was not increased by subsequent recrystallization.

Ethylsulfamide was a colorless crystalline material, readily soluble in water, ethyl acetate, and acetone. It dissolved with difficulty in cold benzene, somewhat better in hot. Aqueous solutions of ethylsulfamide were neutral. Ethylsulfamide crystallized from benzene as fine needles, similar to glass wool. On evaporation of solutions in ethyl acetate, ethylsulfamide separated as short prisms. Pure ethylsulfamide melts without decomposition at 33-35° (uncorr.).

0.0057 g substance: 1.088 ml N_2 (15°, 755 mm). Found %: N 22.47. $C_2H_8O_2N_2S$. Calculated %: N 22.57.

SUMMARY

3-Ethylimidosulfamide was made both by action of ethyl iodide on imidosulfamide silver salt and by action of diazoethane on free imidosulfamide. Its properties have been described. By hydrolysis of 3-ethylimidosulfamide we prepared ethylsulfamide and reported its properties.

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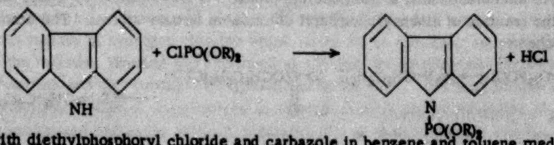
* See Consultants Bureau translation page 709.

ALKYLATION OF AMINES BY DIALKYLPHOSPHORYL CHLORIDES

B. P. Lugovkin and B. A. Arbuzov

As a development of our work [1] on synthesis of ethyl phosphonic acid esters containing heterocyclic radicals, we studied the reaction of diethyl- and dibutylphosphoryl chlorides on carbazole trying to prepare esters of N-phosphono-carbazole.



Experiments with diethylphosphoryl chloride and carbazole in benzene and toluene media did not give positive results. Despite heating for many hours, the carbazole remained unchanged.

When carbazole and diethylphosphoryl chloride were heated without solvent at a temperature of 210°, a vigorous reaction took place with evolution of ethyl chloride and hydrogen chloride. The reaction results were somewhat unexpected. N-ethylcarbazole was separated to the extent of 25%. In the case of reaction with dibutylphosphoryl chloride, N-butylcarbazole, in the amount of 29%, was separated.

Having come upon this interesting case of alkylation by dialkylphosphoryl chlorides, we extended the study to include reaction of dialkylphosphoryl chlorides with other materials containing primary and secondary amino groups. When diphenylamine was heated with dimethylphosphoryl or diethylphosphoryl chlorides a violent reaction occurred: the corresponding alkyl halide and hydrogen chloride were liberated, and N-methyldiphenylamine (yield 69% of theoretical) or N-ethyldiphenylamine (yield 83% of theoretical) was formed.

The large yields of N-substituted diphenylamines gives this reaction interest from the point of view of synthesis, because other methods for preparing alkyldiphenylamines do not give high yields (with diethyl sulfate the yield of N-ethyldiphenylamine is 39% [2]). The acid chlorides of dialkylphosphoric acids are available, nowadays, in view of the method for their preparation by chlorination of dialkylphosphoric acids.

Of the amines with primary amino groups we took aniline and β-naphthylamine. The reaction with aniline took place in two stages. The first stage occurred during heating to 110-125° and was associated with liberation of the alkyl (ethyl) chloride and hydrogen chloride. The second stage took place at 190° and was accompanied by evolution of considerable heat. As a result of the action of excess diethylphosphoryl chloride we obtained diethylaniline with a yield 87% of theoretical.

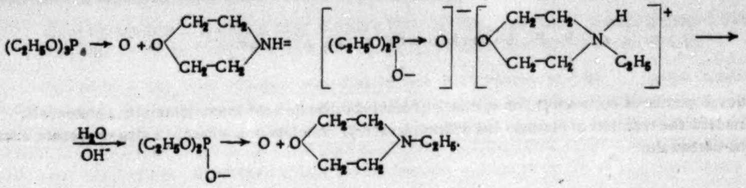
The reaction of diethylphosphoryl chloride on β-naphthylamine proceeded similarly. As a result we obtained N-diethyl-β-naphthylamine with a yield 88% of theoretical. Unheated α-aminopyridine and dimethylphosphoryl chloride reacted violently and resulted in a temperature rise to 230°. N-methyl-pyridone-imine was separated from the reaction products in a 29% of theoretical yield.

In order to examine the nature of the reaction of dialkylphosphoryl chlorides on amides, we performed an experiment on the action of dimethylphosphoryl chloride on benzamide. As a result of this experiment, we separated N-methylbenzamide to the extent of 34% of the theoretical yield.

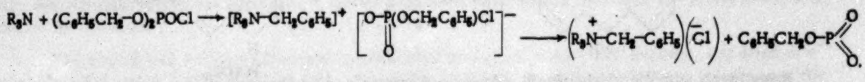
The alkylation reaction using organic derivatives of phosphoric acid does not appear new. Completely esterified phosphoric acid, in the presence of alcoholates, alkylates alcohols [3] and phenols [4]. Alkylation of amines by completely esterified phosphoric acid has been described. Billman, Radike, and Mundy [5] alkylated aniline and α- and β-naphthylamines using fully esterified phosphoric acid and prepared the corresponding dialkylarylamines in good yield according to the equation:

$$3Ar{-}NH_2 + 2(RO)_3PO \longrightarrow 3Ar{-}N(R)_2 + 2H_3PO_4.$$

Rueggerberg and Chernack [3] prepared N-ethylmorpholine from morpholine and triethyl phosphate. Rueggerberg and Chernack assume the formation of ammonium salts in reaction of an amine with phosphoric acid esters. The latter, under the action of alkali, alkylates the amine.



Formation of ammonium salts as intermediate products is also assumed by Todd, Baddiley, Clark, and Michalski [6] for the reaction of dibenzylphosphoryl chloride on tertiary amines. The ammonium salt decomposes according to the scheme:



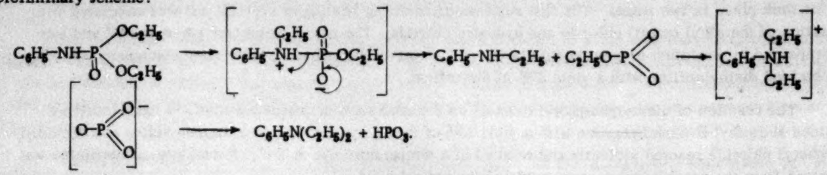
As far as the mechanism of amine alkylation by reaction with dialkylphosphoryl chloride is concerned, although it is given in the present paper, we do not regard it as explained.

A. E. Arbuzov and B. P. Lugovkin [7], and McCombie, Saunders, and Stacey [8] have shown that the acid chlorides of dialkylphosphoric acids react with aniline to form diethylphosphoric acid anilides and aniline hydrochloride. Evidently, these products must form first before the reaction described in the present paper.

In order to investigate the possibility of forming alkylated amines from dialkylphosphoric acid anilides on heating, we performed a test in which we heated the anilide of diethylphosphoric acid. When heated to 230° a violent reaction took place, and the liquid separated into two layers. On cooling the upper layer was an oily liquid while the lower layer was a solid glassy material. Treatment of the solid material with alkali gave an additional quantity of the oily product. This oily material was shown to be diethylaniline. Yield 85.2% of theoretical. Heating diethylphosphoric acid anilide in presence of 2 moles of aniline hydrochloride leads to formation of ethylaniline.

It thus seems that amine alkylation, in the given cases, takes place via thermal decomposition of initially formed anilides.

With regard to the manner of formation of diethylaniline from the anilide, we propose the following, preliminary scheme:



EXPERIMENTAL

Reaction of diethylphosphoryl chloride and carbazole. Test I. To 10 g carbazole in 40 ml dry benzene we added 18.2 g diethylphosphoryl chloride (b.p. 82° at 11 mm, n_D^{20} 1.4169, d_{20}^{20} 1.1953 [9]). This was heated at the boiling point of benzene for 6 hours. After distillation of benzene, we recovered the starting materials, as follows: 8.3 g carbazole (m.p. 238°, mixture test 238°) and 9.7 g acid chloride (b.p. 77° at 7 mm, n_D^{20} 1.4185, d_{20}^{20} 1.1937.

Test II. A mixture of 9.7 g carbazole, 12.8 g acid chloride, 10 g freshly distilled dimethylaniline, and 40 ml dry toluene was heated at the temperature of boiling toluene for 6 hours. After an hour of heating the reaction mixture separated into two layers. We extracted from the toluene solution 1 g carbazole and 3 g dimethylaniline (b.p. 61-62° at 5 mm, n_D^{20} 1.5442, d_{20}^{20} 0.9630). By treating the lower layer with water we separated 8.3 g unchanged carbazole, i.e., a total of 9.3 g carbazole recovered (m.p. 237-238°, mixture test 237-238°). On alkalization with NaOH, 5 g dimethylaniline was separated.

Test III. 9 g acid chloride was added to 6.8 g carbazole. On heating (in a Claissen flask) on a Wood's metal bath, a violent reaction took place with separation of C_2H_5Cl and HCl; the temperature rose to 210°*. The reaction product was dissolved in absolute alcohol with boiling. Extended cooling (to minus 10°, on the average) partially separated the unchanged carbazole. The recovered carbazole weighed 1.2 g (m.p. 234°). After distillation of the alcohol, the residue, which was a thick liquid, was vacuum distilled at 5 mm and 167-169°. An oily liquid (3.8 g) was distilled which crystallized on cooling. After recrystallization from alcohol we obtained 2 g (25%) N-ethyl-carbazole. The picrate, recrystallized from alcohol, formed dark-red-colored small needles which melted at 97-98°. A mixture test with synthetic N-ethylcarbazole (m.p. 100°) melted at 100-101°. The N-ethylcarbazole (m.p. 100°) melted at 100-101°. The N-ethylcarbazole separated by decomposing the picrate by an aqueous solution of ammonia melted at 68-69° (mixture test).

Reaction of di-n-butylphosphoryl chloride on carbazole. We added to 6 g carbazole 8.4 g di-n-butyl phosphate acid chloride (b.p. 117° at 8 mm, n_D^{20} 1.4310, d_{20}^{20} 1.0824 [10]). At a temperature of 170-175° a reaction took place with release of hydrogen chloride which lasted for 15 minutes. We added an additional 5.3 g acid chloride to the residue. Heating was continued at 135-140° for 45 minutes. On distillation under a 3 mm vacuum a crystalline and oily product (7.3 g) distilled at 200-208°. The tarry residue (5.4 g) was not investigated. The distilled material was dissolved in absolute alcohol and on extensive cooling (on the average to minus 10°) unchanged carbazole partially separated (2.8 g, m.p. of picrate 179-181°; mixture test 180°; lit. values 182°, 186°). Following distillation of the alcohol, the thick liquid was again distilled under 5 mm vacuum at 210-218°. We distilled 2.3 g or 28.7%. N-n-butylcarbazole, which was completely converted to the picrate in alcoholic solution. The picrate formed ruby-red long needles melting at 88° (following recrystallization from alcohol). A mixture test with the picrate of synthetic N-n-butylcarbazole (m.p. 89°) melted at 89°.

Heating tests on diethylphosphoryl and dimethylphosphoryl chlorides. 12 g diethylphosphate acid chloride was heated on a Wood's metal bath. At a temperature (in the flask) of 150-160° a vigorous release of ethyl chloride (burning with a green color) and hydrogen chloride (NH_4Cl) took place. The gaseous products weakly decolorized bromine water ($CH_2=CH_2$). Unchanged acid chloride was not observed after an hour of heating. The residue, which was a colorless syrupy liquid, was not investigated. Decomposition of the acid chloride of dimethyl phosphate (b.p. 64-65° at 10 mm, n_D^{20} 1.4118, d_{20}^{20} 1.3455 [11]) took place at 100° with mild release of methyl chloride and hydrogen chloride. At temperatures of 140-145°, vigorous liberation of methyl chloride and hydrogen chloride occurred, during which bromine water was weakly decolorized. The residue was also a syrupy liquid.

Reaction of diethylphosphate acid chloride with diphenylamine. On heating 8.3 g diphenylamine (dried at 120°) with 12.2 acid chloride at 140-155° a violent reaction took place with release of ethyl chloride and hydrogen chloride. The mixture was heated at 155-165° for 45 minutes (until evolution of gaseous products ceased). Two phases were formed: the upper was an oily liquid and the lower a syrup which solidified on cooling. After separation of the upper layer, the residue was treated with a concentrated soda solution; the oily liquid which formed was combined with the main product. An ether extract was prepared which was dried with sodium sulfate.

N-Ethyldiphenylamine was vacuum distilled at 147-148° (11-12 mm) as a colorless oily liquid; n_D^{20} 1.6085, d_{20}^{20} 1.0386. Yield 8 g, 82.7% of theoretical. N-Ethyldiphenylamine on redistillation at 147° (10 mm) gave n_D^{20} 1.6095, d_{20}^{20} 1.0396.

To 1 g N-ethyldiphenylamine (once distilled), dissolved in 5 ml dry chloroform, we added 1.6 g bromine in 5 ml dry chloroform dropwise with cooling (in snow). The mixture was treated with a concentrated soda solution, dried with calcium chloride, and the chloroform evaporated. By recrystallization from a mixture of benzene and petroleum ether, we obtained 1.6 g (theoretical quantity is 1.8 g) N-ethyldiphenylamine dibromide melting at 107-108°.

0.1106 g substance: 0.1160 g AgBr(Carius.) Found %: Br 44.63. $C_{14}H_{13}NBr_2$. Calculated %: Br 45.04.

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* Temperatures in all of the tests were measured in the reaction mixture.

Literature constants for N-ethyldiphenylamine are: b.p. 149-150° at 10 mm, dibromide (p,p'-) m.p. 107-108° [12].

Reaction of dimethylphosphoryl chloride with diphenylamine. On heating 9 g diphenylamine and 11.5 g acid chloride to a temperature of 110-115°, methyl chloride and hydrogen chloride were liberated. At 120-125° a violent reaction occurred which raised the temperature to 170° (without heat). The resulting product was worked up in the same way as in the diethylphosphate experiment. N-Methyldiphenylamine was distilled at 153-155° (15-16 mm) as a colorless oily liquid; n_D^{20} 1.6238; d_{20}^{20} 1.0596; yield 6.7 g or 68.8% of theoretical. On redistillation, b.p. was 147-148° at 11 mm, n_D^{20} 1.6230, d_{20}^{20} 1.0572. We prepared N-methyldiphenylamine dibromide (under the same conditions as for N-ethyldiphenylamine); colorless small needles melting at 119° (after recrystallizing twice from alcohol).

Literature constants for N-methyldiphenylamine are: b.p. 145-146° at 10 mm, 148° at 13 mm, dibromide (p,p'-) m.p. 120° [12].

Reaction of diethylphosphoryl chloride and aniline. We added 37 g acid chloride to 10 g aniline (freshly distilled), during this the temperature rose to 95° with release of ethyl chloride and hydrogen chloride. When heated to 110-125° it frothed vigorously and released considerable ethyl chloride and a small amount of hydrogen chloride. It was heated for 15 minutes (until evolution of gaseous products ceased). The mix was cooled to 110° and an additional 18.5 g acid chloride added. It was again heated to 110-120° for 15 minutes and then to 160-170° for 15 minutes; on continuing the heating to 190° a violent reaction ensued which raised the temperature to 230° (without further heating); liberation of gaseous materials stopped. The glassy-appearing reaction product was dissolved in 30 ml water with heating; on cooling, the solution was neutralized, using a concentrated [illegible] solution of potassium hydroxide [illegible]. The oily liquid which formed was separated, and the water solution extracted with ether; both were dried with potassium hydroxide, The reaction product distilled at 91-94° (10 mm) as a colorless oily liquid; n_D^{20} 1.5410, n_D^{22} 1.5400, d_{20}^{20} 0.9407. The picrate which formed yellowish-green colored crystals melting at 137-138° melted at 138-139° after recrystallization from alcohol. A mixture test with the picrate of N-monoethylaniline (yellow color, m.p. 136-136.5°) gave a depressed melting point (110-115°).

The distillation gave 14 g diethylaniline, or 87.5% of theoretical. On redistillation (12.7 g) diethylaniline was obtained in the following fractions at 10 mm:

I. 88-89°, n_D^{20} 1.5440, n_D^{22} 1.5435, d_{20}^{20} 0.9518 (1.8 g); picrate had a yellow-green color with m.p. 138-139°.

II. 89-90°, n_D^{20} 1.5410, n_D^{22} 1.5400, d_{20}^{20} 0.9402 (10.1 g); picrate had a yellow-green color with m.p. 138-139°.

Picrates of the I and II fractions had a depressed melting point (110-115°) when melted with the picrate of monoethylaniline (m.p. 136-136.5°).

Literature constants are [13]: aniline; b.p, 69° at 10 mm, n_D^{22} 1.5848, d_{20}^{20} 1.0219; picrate light yellow in color, m.p. 181°; monoethylaniline: b.p. 84° at 10 mm, 206° at 760 mm, d_{15}^{18} 0.9705, n_D^{20} 1.5559; picrate, yellow in color, m.p. 132°; diethylaniline: b.p. 215-216°, 92° at 10 mm, n_D^{22} 1.5410, d_{15}^{18} 0.9350; picrate, yellowish green color, m.p. 142° and 135-136°.

Reaction of diethylphosphoryl chloride on β-naphthylamine. 24 g acid chloride was added to 10 g β-naphthylamine (dried at 110°); the temperature rose to 50°. On heating to 120° vigorous frothing and evolution of ethyl chloride and hydrogen chloride took place. The temperature was held to 120-130° for 15 minutes (until frothing became weak). On heating to 180-185° a violent reaction (with release of ethyl chloride together with mild evolution of hydrogen chloride) took place; the temperature rose (without further heating) to 260°. The reaction mixture was a very thick liquid. The mixture was cooled to 65° and an additional 24 g acid chloride added. The reaction was then carried out for 15 minutes at 120-130° and for 40 minutes at 175-185° (until evolution of gaseous products became weak). After working up (see the experiment with aniline) the product gave on vacuum distillation at 10 mm the following fractions:

I. 167-168°; light yellow-colored liquid with blue fluorescence, n_D^{20} 1.6270, 1.4 g.

II. 169-172°; light yellow-colored liquid with blue fluorescence, n_D^{20} 1.6335, d_{20}^{20} 1.0215. 12.2 g N-diethylnaphthylamine was distilled, or 87.7% of theoretical. The picrate formed yellow colored crystals which melted at 151-152°. The melting point did not change on recrystallization from alcohol.

We prepared the hydrochloride of N-diethyl-β-naphthylamine (by passing dry hydrogen chloride through a dry ether solution); it melted at 169-170°. After recrystallization from a mixture of chloroform and dry benzene it melted at 175°.

0.0932 g substance: 0.0574 g AgCl. Found %: Cl 15.23. $C_{14}H_{17}N \cdot HCl$. Calculated %: Cl 15.06.

Literature constants [14] are: β-naphthylamine, b.p. 306°; N-monoethylnaphthylamine, b.p. 315-316°; 167° at 10 mm; N-diethylnaphthylamine, b.p. 316°; hydrochloride, m.p. 175° or 177-178°.

Reaction of dimethylphosphoryl chloride on α-aminopyridine. 16 g acid chloride was added to 10 g α-aminopyridine (dried at 110°); a very violent reaction ensued with liberation of methyl chloride and mild evolution of hydrogen chloride, the temperature rose from 20° to 230°. The mixture was cooled to 95° and 16 g additional acid chloride added. It was heated at 95-120° for 15 minutes with violent release of methyl chloride and mild evolution of hydrogen chloride. The glassy reaction product was dissolved in 60 ml water with heating, and on cooling was neutralized by water and then by potassium hydroxide. It was extracted (with thorough stirring of the pasty mass) using several portions of ether (total volume 130 ml). After drying over potassium hydroxide and distillation of the ether an oily reddish-brown liquid was obtained; the latter was distilled with negligible residue (b.p. 107-110° at 18 mm, yellow colored liquid, yield 3.3 g or 28.7% of N-methylpyridone-imine).

2.5 g of the fraction was dissolved in 10 ml alcohol and 3.5 g picric acid added, a yellow colored picrate precipitated at once. 4.4 g of picrate were separated, m.p. 170-180°. After recrystallization from alcohol (130 ml) the melting point was 197-198°, 3 g. A second recrystallization from alcohol gave m.p. 199-200°, yellowish green in color. A mixture test with the picrate of synthetic N-methylpyridone-imine (m.p. 199-200°) melted without depression at 199-200°. From the mother liquor (of the picrate preparation) we obtained a yellow colored picrate having m.p. 158-167° (0.7 g). In view of its small quantity, this picrate was not identified. The orange colored picrate of methyl-α-aminopyridine was not observed. Also unobserved was the picrate of unchanged α-aminopyridine.

Literature values [15]: methyl-α-aminopyridine: b.p. 100-102° at 18 mm; orange colored picrate, m.p. 190° or 193-194°; N-methylpyridone-imine: b.p. 108° at 16 mm; yellowish green colored picrate, m.p. 199-201°; dimethyl-α-aminopyridine: b.p. 196°; yellow colored picrate, m.p. 182°; N-methylpyridonemethylimine: b.p. 128° at 38 mm; yellow colored picrate, m.p. 160°.

Reaction of dimethylphosphoryl chloride on benzamide. 14.5 g acid chloride was added to 6 g benzamide (dried at 120°). A violent reaction occurred on heating to 80° with release of methyl chloride and hydrogen chloride; the temperature rose to 120° without further heating. When the reaction was finished, in about 15 minutes, we added an additional 10 g acid chloride. After 15 minutes of heating at 120-140°, heating was continued at 170-180° (for 5 minutes until evolution of gaseous products ceased). The reaction product was treated with a concentrated solution of potassium hydroxide and the oily liquid layer which formed separated using benzene extraction; the extract was dried over sodium sulfate. The benzene was vaporized and the reaction product then distilled under vacuum as follows:

Fraction I: 88-170° at 15 mm(most of it at 88°); colorless liquid 0.8 g.

Fraction II: 174-178° at 15 mm; very thick liquid, partially crystallized, 4.5 g. The crystalline product was filtered after cooling. We obtained 1.5 g N-methylbenzamide with m.p. 71-73°. Following crystallization from aqueous alcohol its m.p. was 79-80°. The oily liquid product was redistilled, and it came over completely at 175-177° (16 mm) as a thick liquid. The crystals which formed on slow cooling were pressed on a clay plate; we obtained an additional 0.8 g N-methylbenzamide with m.p. 75-77°. A mixture test with benzamide melted with depression at 62°. The total yield of N-methylbenzamide was 2.3 g, or 34.4% of theoretical.

Literature constants [16]; N-methylbenzamide, b.p. 167° at 11 mm, m.p. 75, 78 and 82°; N-dimethylbenzamide, b.p. 132° at 15 mm, m.p. 41-42°.

Experiment on heating diethylphosphoric acid anilide with aniline hydrochloride. 10.9 g diethylphosphate anilide (m.p. 95-96°) • and 12.8 g (2 moles) aniline hydrochloride were heated on a Wood's metal bath. At a temperature of 100-110° (in the flask) ethyl chloride was energetically evolved with frothing. After 5 minutes

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• Diethylphosphate anilide was prepared by the Arbusov-Lugovkin method (see [7]). 20 g acid chloride was added to 21.2 g aniline (freshly distilled). The temperature rose to 144°. We obtained 15.6 g (59.6%) anilide and 10.9 g (73.7%) aniline hydrochloride.

the temperature was increased by heating to 145-156° over a 15 minute period with vigorous release of ethyl chloride. On heating to 200-225° the ethyl chloride evolution (which resulted in effervescence of the reaction mixture) stopped. Evolution of hydrogen chloride did not occur. After suitable working up (see experiment with aniline) and a second vacuum distillation at 10 mm, we separated the following fractions:

I. 72-75°; oily liquid smelling like aniline, n_D^{20} 1.5785, n_D^{22} 1.5779, d_{20}^{20} 1.0040; light yellow color picrate, m.p. 181-182° (from ether); after recrystallization from alcohol its m.p. was 184-185°; mixture test with aniline picrate melted without depression; 5.7 g aniline distilled.

II. 75-77°; n_D^{20} 1.5728, d_{20}^{20} 0.9949 (2.1 g); the picrate was the same as for fraction I; total aniline distilled was 7.8 g (according to the theory 8.83 g should be obtained from the aniline hydrochloride), or 88.3%.

III. 80-82°; colorless oily liquid (with weak blue fluorescence) n_D^{20} 1.5640, n_D^{22} 1.5630, d_{20}^{20} 0.9771; yellow colored crystalline picrate with m.p. 136-136.5° (from ether); after two recrystallizations from alcohol the melting point was unchanged. A mixture test with the picrate of diethylaniline (m.p. 138-139°) melted with depression (110-115). 5.7 g monoethylaniline was distilled (99.0%).

Literature constants: refer to experiment with aniline.

Test on heating the anilide of diethylphosphoric acid. 8.1 g diethylphosphate anilide (m.p. 95-96°) was heated at a temperature of 120-130° for 30 minutes; at 160-170° for 15 minutes (it was somewhat violent), and when heated to 230° a violent reaction took place with effervescence and separation into two layers; the temperature rose (without further heating) to 240°. The material was rapidly cooled to 200° and again heated to 240°. On cooling, the upper layer was an oily liquid insoluble in water with a diethylaniline odor; the lower layer, a glassy solid material, was worked up in a concentrated solution of potassium hydroxide, the oily liquid which separated was combined with the upper layer, the residue was extracted with ether, and the extract dried over KOH. The reaction product completely distilled at 86-87° (10 mm) as an oily liquid. On redistillation its b.p. was 86° at 10 mm, n_D^{20} 1.5434, n_D^{22} 1.5420, d_{20}^{20} 0.9387. Yellowish-green crystalline picrate (from ether) had m.p. 138-139° (after two recrystallizations from alcohol). A mixture test with the picrate of diethylaniline (experiment with aniline) melted at 139-140°. 4.5 g diethylaniline was distilled (85.2%).

Literature constants: see the aniline experiment.

SUMMARY

1. We studied the reaction of diethylphosphoryl chloride and dibutylphosphoryl chloride on carbazole. It was shown that reaction takes place when the components are heated above 200°, and that as a result N-ethyl- and N-butyl-carbazole are obtained, respectively.

2. The alkylating effect of dialkylphosphoryl chlorides has been stated with regard to aniline, β-naphthylamine, diphenylamine, and α-aminopyridines. As a result of these reactions, we obtained N-diethylaniline (87%), N-diethyl-β-naphthylamine (88%), N-ethyldiphenylamine (83%), N-methyldiphenylamine (69%), and N-methylpyridoneimine (29%), respectively.

3. Alkylation by dialkylphosphoryl chlorides takes place even in the case of amides, as has been shown using benzamide as an example.

4. In order to explain the mechanism of the alkylating action of acid chlorides we studied the effect of temperature on diethylphosphoric acid anilide. It was shown that heating it to 230° formed dimethylaniline (85%). A preliminary scheme for decomposition of diethylphosphoric acid anilide has been presented.

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THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO UNSATURATED COMPOUNDS

VIII. ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO ETHYLIDENE- AND BENZYLIDENE-MALONIC AND ACETOACETIC ESTERS

A. N. Pudovik

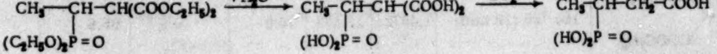
In a series of earlier papers [1] we showed that dialkylphosphorous acids add very readily to α,β-unsaturated ketones, aldehydes, nitriles, esters of unsaturated acids, and esters of vinyl alcohols with formation of the corresponding saturated phosphonic ester derivatives. The preparation of many derivatives of phosphonic esters by this new method of synthesis is simple to perform, is practicable with regard to initial materials, and gives almost quantitative yields in most cases. In the course of our earlier work on addition of dialkylphosphorous acids to esters of α,β-unsaturated acids which contained one activating group of the electronophilic type, we became interested in investigating the addition reaction of dialkylphosphorous acids to asymmetric unsaturated compounds containing two identical or different groups of the electronophilic type on a single carbon atom. It may be supposed that addition of dialkylphosphorous acids to compounds of this type would, on account of the simultaneous action of both activating groups on the double bond, proceed no less, and possibly even more, intensively than it did to the compounds studied earlier having one activating group. For this purpose in this present research we undertook to investigate the addition reaction of dialkylphosphorous acids to ethylidene-malonic ester, isopropylideneacetoacetic ester, benzylidene-malonic ester, and benzylideneacetoacetic ester. The reaction was carried out in the presence of catalysts – alkali metal alcoholates.

In order to avoid exchange of radicals in the process of reaction between the dialkylphosphorous acid being added and the alkali metal alcoholate, the latter was prepared from an alcohol containing the same radical as was present in the dialkylphosphorous acid.

Addition of dimethylphosphorous, diethylphosphorous, diisobutylphosphorous, and dibutylphosphorous acids to ethylidenemalonic ester was accompanied by vigorous heating of the reaction mixture, sufficient in some cases to cause boiling. Addition of the same dialkylphosphorous acids to ethylideneacetoacetic ester took place considerably more gently, accompanied by comparatively little heating of the reaction mix.

The yields of the addition products, which were the several ethyl esters of α-(dialkylphosphono)-ethylmalonic and α-(dialkylphosphono)-ethylacetoacetic acids, ranged from 65 to 87%. The formulas, constants, yields, and analytical results for phosphorous content of the products obtained are given in Table 1.

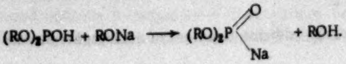
The product from addition of diethylphosphorous acid to ethylidenemalonic ester – the ethyl ester of α-(diethylphosphono)-ethylmalonic acid – was saponified by addition of hydrochloric acid with heating; as a product we obtained β-phosphonobutyric acid with m.p. 140-141°.



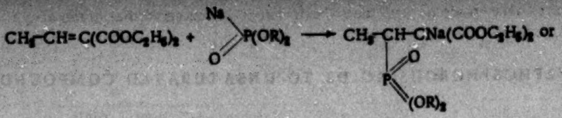
$$CH_3-\underset{(C_2H_5O)_2P=O}{CH}-CH(COOC_2H_5)_2 \xrightarrow{+H_2O} CH_3-\underset{(HO)_2P=O}{CH}-CH(COOH)_2 \xrightarrow{-CO_2} CH_3-\underset{(HO)_2P=O}{CH}-CH_2-COOH$$

The β-phosphonobutyric acid prepared earlier by us, by saponification of β-diethylphosphonobutyric acid ethyl ester, had a melting point of 141-143°. The results which were obtained showed that addition of dialkylphosphorous acids to the double bond of ethylidenemalonic and ethylideneacetoacetic esters takes place in such a way that the dialkylphosphonic group adds to the β-carbon atom of the double bond, not carrying an activating group.

The full course of reaction for addition of dialkylphosphorous acids to ethylidenemalonic ester may be shown by the following scheme:



$$(RO)_2POH + RONa \longrightarrow (RO)_2P\overset{O}{\underset{Na}{\lessdot}} + ROH.$$



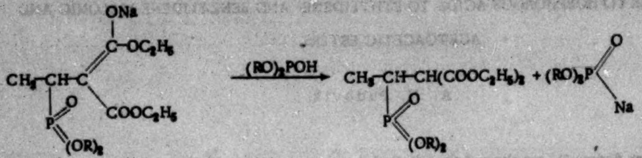
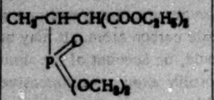
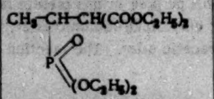
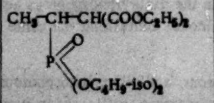
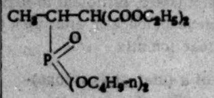
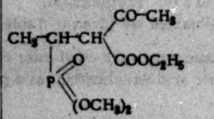
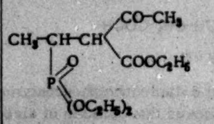


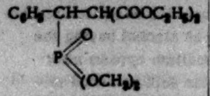
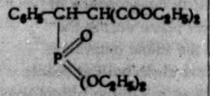
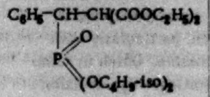
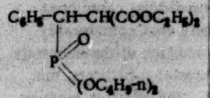
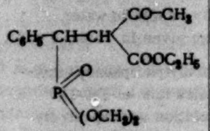
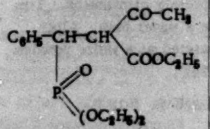
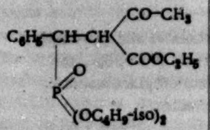
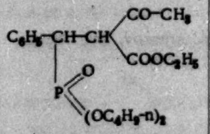
TABLE 1

No.	Formula	Boiling point	n_D^{20}	d_4^{20}	Phosphorous Content, (in %)		Yield (in %)
					found	calculated	
1		181° (13 mm)	1.4462	1.1748	10.3	10.5	85.7
2		180 (11 mm)	1.4427	1.1172	10.1	9.7	87.0
3		198-200 (11 mm)	1.4445	1.0445	8.1,8.3	8.2	66.5
4		203-204 (11 mm)	1.4457	1.0560	8.2,8.2	8.2	78.0
5		164-167 (14 mm)	1.4703	1.1943	11.7	11.7	71.1
6		164-166 (12 mm)	1.4672	1.1473	10.6	10.6	65.6

In addition we investigated addition of dialkylphosphorous acids to benzylidenemalonic ester and to benzylideneacetoacetic ester. The reaction was performed in the same manner as was employed for the corresponding ethylidene derivative. This reaction also took place quite vigorously: with the lower dialkylphosphorous acids we observed boiling of the reaction mixture. The constants, yields, and analytical results for phosphorous content of all the ethyl esters of phenyldialkylphosphonomethylmalonic and phenyldialkylphosphonomethylacetoacetic acids are given in Table 2.

We may propose a scheme for the full course of the addition reactions of dialkylphosphorous acids to ethylideneacetoacetic ester and to benzylidene- malonic and acetoacetic esters analogous to that given above for addition to ethylidenemalonic ester.

TABLE 2

No.	Formula	Boiling point	n_D^{20}	d_4^{20}	Phosphorous Content, (in %)		Yield (in %)
					found	calculated	
1	 $C_6H_5-\underset{P(O)(OCH_3)_2}{CH}-CH(COOC_2H_5)_2$	200-202° (3 mm)	1.4975	1.2063	9.4	9.2	79.4
2	 $C_6H_5-\underset{P(O)(OC_2H_5)_2}{CH}-CH(COOC_2H_5)_2$	212-214 (11 mm)	1.4911	1.1364	7.9,7.9	8.0	70.0
3	 $C_6H_5-\underset{P(O)(OC_4H_9\text{-iso})_2}{CH}-CH(COOC_2H_5)_2$	219 (14 mm)	1.4812	1.0475	6.8	7.0	80.9
4	 $C_6H_5-\underset{P(O)(OC_4H_9\text{-n})_2}{CH}-CH(COOC_2H_5)_2$	218-220 (11 mm)	1.4820	–	7.2	7.0	75.6
5	 $C_6H_5-\underset{P(O)(OCH_3)_2}{CH}-CH(CO{-}CH_3)(COOC_2H_5)$	193-195 (6 mm)	1.5295	1.2096	9.2, 9.4	9.2	65.4
6	 $C_6H_5-\underset{P(O)(OC_2H_5)_2}{CH}-CH(CO{-}CH_3)(COOC_2H_5)$	204-206 (7 mm)	1.5195	1.1836	8.9	8.7	56.0
7	 $C_6H_5-\underset{P(O)(OC_4H_9\text{-iso})_2}{CH}-CH(CO{-}CH_3)(COOC_2H_5)$	204-205 (6 mm)	1.4970	1.1104	7.8	7.5	66.6
8	 $C_6H_5-\underset{P(O)(OC_4H_9\text{-n})_2}{CH}-CH(CO{-}CH_3)(COOC_2H_5)$	195-197 (1.5 mm)	1.4808	1.0441	7.7	7.5	67.8

In conclusion we performed experiments on addition of dialkylphosphorous acids to isopropylidenemalonic and isopropylideneacetoacetic esters. It was found, that even in these cases, despite the possible shielding effect of the two methyl groups attached to the β-carbon atom with the consequent reduction of its electronophilic nature as compared with the β-carbon atom in ethylidene- and benzylidene- derivatives, the addition reaction took place sufficiently vigorously with significant heating of the reaction mixture. However, it was not possible to separate the addition products either by direct distillation of the reaction mixture or by working up in acetic acid and water; on heating a gradual increase in viscosity of reaction mass occurred, and it became converted progressively into a glassy almost solid product.

EXPERIMENTAL

General method for performing the addition reaction. The reaction of addition of dialkylphosphorous acids to ethylidenemalonic, ethylideneacetoacetic, benzylidenemalonic, benzylideneacetoacetic, isopropylidenemalonic, and isopropylideneacetoacetic esters was performed by the following general method. To 8-10 g ester was added an equimolar quantity of dialkylphosphorous acid and a saturated alcoholic solution of sodium alcoholate was then added slowly to the mixture. The sodium alcoholate was prepared using an alcohol having the same radical as was present in the dialkylphosphorous acid being added. This latter condition appears most essential in performing the reaction under discussion; in the event that dialkylphosphorous acid be added to some idene derivative in presence of a sodium alcoholate containing a different radical, in consequence of exchange of radicals between the alcoholate and the dialkylphosphorous acid which takes place during the time of reaction [3], a mixture of addition products of both dialkylphosphorous acids to the idene derivative can form; separation of the mixture by distillation does not appear possible because of the close boiling points. In this latter circumstance separation of the addition products is possible only with a spread in boiling points and generally with increased phosphorous content compared with the theoretical value (particularly with use of sodium methylate for all of the reactions). Addition of the alcoholic alcoholate solution, particularly with lower dialkylphosphorous acids, was accompanied by vigorous heating of the reaction mixture, which in some cases (most frequently when the alcoholate was added rapidly) was sufficient to cause boiling. The addition of the alcoholate was continued in all cases until further addition to the reaction mixture did not cause heat release. In performing the reaction with the higher dialkylphosphorous acids we ordinarily used considerably larger quantities of the alcoholate than with the lower dialkylphosphorous acids. After addition of the necessary quantity of alcoholate solution, which varied in our experiments from several drops to several milliliters, the reaction mixture was heated for a short time on a water bath and then vacuum distilled. The addition products were colorless or lightly straw colored viscous liquids; several of them were quite readily soluble in water. Constants, yields, and the results of phosphorous analyses for all the prepared products are given in Tables 1 and 2.

Saponification of α-(diethylphosphono)-ethylmalonic acid ethyl ester. 3 g α-(diethylphosphono)-ethylmalonic acid ethyl ester and 25 ml diluted (1:1) hydrochloric acid were heated in a sealed tube at 130-140° for a period of 10 hours. After opening the tube and removing the ethyl chloride, the solution was repeatedly evaporated, with periodic addition of distilled water – until hydrogen chloride was completely eliminated. The solution was then boiled a short while with animal charcoal, filtered, and evaporated on a water bath. After cooling and prolonged standing in the air, a precipitate of β-phosphonobutyric acid separated as a white powder. It was recrystallized twice from water to yield β-phosphonobutyric acid with m.p. 140-141°.

Phosphorous analysis, by Neyman method. Found %: P 18.2. $C_4H_9O_5P$. Calculated %: P 18.5.

SUMMARY

It has been shown that dialkylphosphorous acids in presence of alkali metal alcoholates add extremely readily to ethylidene- and benzylidene- malonic and acetoacetic esters to form, with yields of 65-80%, the corresponding ethyl esters of α-(dialkylphosphono)-ethylmalonic, and α-(dialkylphosphono)-ethylacetoacetic, phenyldialkylphosphono-methylmalonic, and phenyldialkylphosphono-methylacetoacetic acids.

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* See Consultants Bureau English translation p. 525, 531, 537, 1189, 1415.

** See Consultants Bureau English translation p. 1189.

*** See Consultants Bureau English translation p. 531.

THE ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO UNSATURATED COMPOUNDS

IX. REACTION OF SODIUM DIETHYLPHOSPHITE WITH ALLYL BROMIDE AND WITH ISOMERIC CHLOROBUTENES

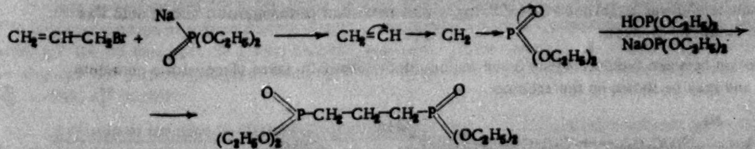
A. N. Pudovik and M. M. Ftolova

In one of the contributions, relating to a study of the allyl rearrangement [1], we described a reaction between salts of dialkylphosphorous acid and the isomeric methoxychloropentenes; it was shown then that the reaction, depending on conditions, leads to formation of products which contain one or two dialkylphosphono groups. Using indirect methods, we established the conclusion that in this latter case addition of a molecule of dialkylphosphorous acid to the double bond takes place with formation of methoxydiethylphosphonopentene as the first stage of the reaction. Furthermore, in a special series of papers [2], one of us has shown that addition of dialkylphosphorous acid to unsaturated electronophilic reagents was a general reaction using: unsaturated nitriles, ketones, aldehydes, carboxylic acid esters, and esters of vinyl alcohols. We regard this reaction as the foundation for the development of a new, very simple and convenient, method for the synthesis of esters of various phosphonic acid derivatives.

In 1950 Rueggerberg, Chernack, and Rose [3], who were evidently unfamiliar with our work on the action of dialkylphosphorous acid salts on the isomeric methoxychloropentenes [1], described the reaction between sodium dibutylphosphite and allyl bromide and claimed to have prepared a high-boiling product, which they supposed, in accordance with the analytical data, to be either 1,2- or 1,3-di-(dibutylphosphono)-propane. They were not able to prepare the dibutyl ester of allylphosphonic acid, the synthesis of which appears to have been their aim. Regarding this reaction of allyl halides with salts of dialkylphosphorous acids as of considerable theoretical interest, both in relation to explaining the mechanism of the addition reaction as well as of the allyl rearrangement, we resumed our much earlier study and in the present work decided to study in greater detail the reactions between allyl bromide and the isomeric chlorobutenes with sodium diethylphosphite.

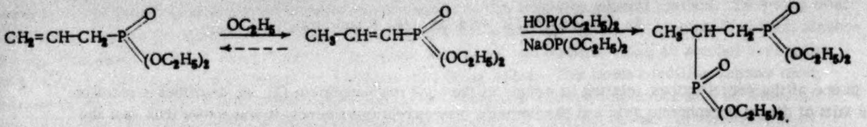
By performing the reaction between allyl bromide and sodium diethylphosphite in the minimum amount of benzene needed to dissolve sodium diethylphosphite, we obtained two high-boiling products. The first of these, which was formed with a 30.8% yield had a b.p. of 160-162° (3 mm), n_D^{20} 1.4430, d_4^{20} 1.1114; the other was prepared with a 11.2% yield and had a b.p. of 185-186° (3 mm), n_D^{20} 1.4500, d_4^{20} 1.1227. The phosphorous content of both products satisfied the same empirical formula $C_{11}H_{26}O_6P_2$. In accordance with studies made by us earlier it may be presumed that formation of these isomeric compounds results from addition of diethylphosphorous acid to the ethyl ester of allylphosphonic acid, i.e. they correspond to 1,2- and 1,3-di-(diethyl phosphono)-propanes. Actually the higher-boiling isomer, according to its constants, corresponds to 1,3-di-(diethylphosphono)-propane prepared by A. E. Arbuzov and Kushkova [4] and, considerably later, by Ford-Moore [5]. Synthesis of 1,3-di-(diethylphosphono)-propane in both of these cases was accomplished by the method of Academician Arbuzov involving action of trimethylene bromide on the fully ethylated ester of phosphorous acid. According to Ford-Moore, 1,3-di-(diethylphosphono)-propane has a b.p. of 175° (0.8 mm), $n_D^{16.5}$ 1.4508; according to the data of A. E. Arbuzov and Kushkova it boils at 186° at 3 mm and has d_4^{20} 1.12502.

Formation of 1,3-di-(diethylphosphono)-propane in our reaction may be shown by the following scheme:



$$CH_2{=}CH{-}CH_2Br + NaO{-}P(OC_2H_5)_2 \longrightarrow CH_2{=}CH{-}CH_2{-}P(O)(OC_2H_5)_2 \xrightarrow[NaOP(OC_2H_5)_2]{HOP(OC_2H_5)_2} (C_2H_5O)_2P(O){-}CH_2{-}CH_2{-}CH_2{-}P(O)(OC_2H_5)_2$$

With regard to the main reaction product formed (with a b.p. of 160-162° at 3 mm), it evidently was 1,2-di-(diethylphosphono)-propane because it is not possible to form other isomeric products in the reaction under study. It may be supposed that 1,2-di-(diethylphosphono)-propane is formed analogously to 1,3-di-(diethylphosphono)-propane by addition of diethylphosphorous acid to allylphosphonic ester, but in a different order. Naturally, such an assumption is improbable if one takes the polarization character of both reactants into account. It appears considerably more probable, in our opinion, to assume that allylphosphonic ester, which has a mobile three-carbon prototropic system, in the presence of alkoxyl ions which are active proton acceptors first isomerizes into the thermodynamically more stable propenylphosphonic ester, which then, like other α,β-unsaturated electronophilic reagents, readily adds to its double bond a molecule of diethylphosphorous acid.



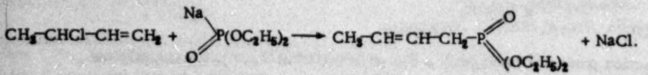
Actually, a series of authors, in particular Kohn and Linstid and their colleagues, have shown [6] that in the system $CH_2{=}CH{-}CH_2X \rightleftarrows CH_3{-}CH{=}CH{-}X$, where X is an activating group of electronophilic character, the equilibrium is completely displaced toward the α,β-unsaturated form; this latter also appears applicable in the case of the system $CH_3{-}CH{=}CH{-}CH_2X \rightleftarrows CH_3CH_2{-}CH{=}CH{-}X$.

Furthermore, we decided to study the effect of reaction conditions on the nature of the course of reaction, and in relation to the reaction products. When the reaction between sodium diethylphosphite acid and allyl bromide was performed with a considerable quantity of free diethylphosphorous acid present in the reaction mixture, (compared with data of the earlier work [1]), it was found that the ethyl ester of allylphosphonic acid was formed as the sole reaction product. Analogous results were obtained, even when an excess of diethylphosphorous acid was not present in the reaction mixture, in the presence of a large quantity of benzene. With comparatively small quantities of benzene in the reaction mixture we obtained all three products: both isomeric di-(diethylphosphono)-propanes as well as the ethyl ester of allylphosphonic acid. Thus, the interesting fact developed that the course of the reaction between allyl bromide and sodium diethylphosphite effectively changes in nature depending on the quantity of diethylphosphorous acid or inert diluent present in the reaction medium. In the presence of large quantities of the latter the reaction stops at the substitution stage, with a minimum content – the addition reaction proceeds almost quantitatively.

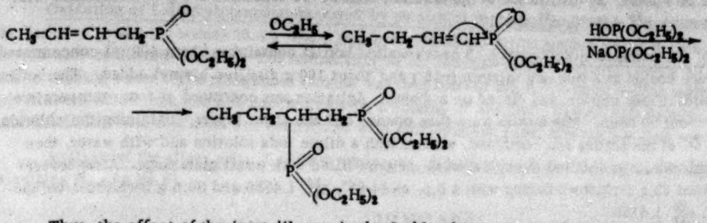
As a development of the last conclusion and in order to fully explain the mechanism of formation of di-dialkylphosphono derivatives in the reaction between allyl halide compounds with salts of dialkylphosphorous acid, we conducted experiments on the direct addition of diethylphosphorous acid to the ethyl ester of allylphosphonic acid. It was found that in the presence of sodium ethylate at 90-100° the reaction goes very slowly, at 130-140° it takes place considerably more rapidly; as a result of heating for three hours we obtained 1,3-di-(diethylphosphono)-propane, b.p. 159-160° (2 mm), n_D^{20} 1.4420, d_4^{20} 1.1117, with 51.6% yield. Isomeric products were not observed. The results of the latter experiment may be regarded as direct evidence of the correctness of the mechanism proposed by us for formation of di-diethylphosphono derivatives in the reaction described above.

In addition, we studied the reaction of sodium diethylphosphite with the isomeric chlorobutenes. As a result of the action of sodium diethylphosphite on an equimolar quantity of 1-chlorobutene-2 in an ether solution we obtained 1-diethylphosphonobutene-2 with a 45.2% yield. The reaction took place very readily and quickly. In performing the analogous reaction with the second chloride – 2-chlorobutene-3 – we found that it took place only very slowly in ether solution; because of this, subsequent tests were performed in a benzene solution. By reaction of sodium diethylphosphite on 2-chlorobutene-3 in the presence either of diethylphosphorous acid or of a large quantity of benzene, we observed the formation of only one product – 1-diethylphosphonobutene-2. Addition of bromine to 1-diethylphosphonobutene-2 gave 1-diethylphosphono-2,3-dibromobutane. The structure of 1-diethylphosphonobutene-2 was established by oxidizing it with potassium permanganate; acetic acid was identified among the oxidation products.

Thus the reaction between 2-chlorobutene-3 and sodium diethylphosphite takes place with a complete allyl rearrangement and may be shown by the scheme:



In performing the reaction between sodium diethylphosphite and 2-chlorobutene-3 with free diethylphosphorous acid and excess benzene absent from the reaction medium, instead of 1-diethylphosphonobutene-2 we obtained the high boiling product 1,2-di-(diethylphosphono)-butane in a 15% yield, b.p. 160-161° (3 mm), n_D^{20} 1.4420, d_4^{20} 1.1014. This same product was obtained in 59.3% yield by direct addition of diethylphosphorous acid to 1-diethylphosphonobutene-2 in the presence of sodium ethylate. For both the first and the second cases, the reaction may be expressed by the following scheme:


$CH_3-CH=CH-CH_2-P(O)(OC_2H_5)_2$
OC_2H_5
$CH_3-CH_2-CH=CH-P(O)(OC_2H_5)_2$
$HOP(OC_2H_5)_2$
$NaOP(OC_2H_5)_2$
$CH_3-CH_2-CH-CH_2-P(O)(OC_2H_5)_2$
$P(O)(OC_2H_5)_2$

Thus, the effect of the inert diluent, in the 3-chlorobutene-2 experiments, on the course of the reaction with salts of dialkylphosphorous acid is completely determined, and the mechanism proposed for formation of di-dialkylphosphono derivatives confirmed.

EXPERIMENTAL

Reaction of sodium diethylphosphite on allyl bromide. Test I. 7.6 g sodium and 50 ml absolute benzene were placed in a round bottom flask fitted with a reflux condenser and dropping funnel; 46 g diethylphosphorous acid was then slowly added. After all the sodium dissolved, with formation of a solution of sodium diethylphosphite, 40 g allyl bromide was gradually added. The reaction took place very violently with considerable heating of the reaction mix. After the entire quantity of allyl bromide had been added, the reaction mixture was heated on a water bath for 3 hours, and later after cooling, treated with a small quantity of water. After separating the upper layer and drying it for a short while over calcium chloride, the benzene was distilled from it; the residue was vacuum distilled. Two products were separated:

1) 1,2-Di-(diethylphosphono)-propane (8 g), b.p. 160-162° (3 mm); n_D^{20} 1.4430; d_4^{20} 1.1114; MR_D 75.18. Calculated 74.74. Found %: P 19.47. $C_{11}H_{26}O_6P_2$. Calculated %: P 19.62.

2) 1,3-Di-(diethylphosphono)-propane (3 g), b.p. 185-186° (3 mm); n_D^{20} 1.4500; d_4^{20} 1.1227; MR_D 75.38. Calculated 74.74. Found %: P 19.71. $C_{11}H_{26}O_6P_2$. Calculated %: P 19.62.

Test II. The reaction was carried out with the same quantities of reactants but with a somewhat larger quantity of benzene. As a result of distillation of the reaction mixture we separated 12.2 g 1,2-di-(diethylphosphono)-propane having a b.p. of 160-162° (3 mm); 7.8 g 1,3-di-(diethylphosphono)-propane with b.p. 185-187° (3 mm); and 11 g diethyl ester of allylphosphonic acid with b.p. 98-100° (12 mm).

Reaction of sodium diethylphosphite on allyl bromide in the presence of excess diethylphosphorous acid. The benzene solution of sodium diethylphosphite was prepared analogously to the foregoing from 3.8 g sodium 45.6 g diethylphosphorous acid, and 30 ml benzene. 20 g allyl bromide was then added to it. After the end of the reaction, the reaction mixture was treated with water, the benzene layer dried with calcium chloride, and then after distillation of the benzene on a water bath the residue was vacuum distilled. We separated 22.7 g diethylphosphorous acid and 7.7 g 1-diethylphosphonopropene-2 with a b.p. of 98-100° (12 mm), n_D^{20} 1.4350, d_4^{20} 1.0370, MR_D 44.80. $C_7H_{15}O_3P\digamma$. Calculated 44.93. Found %: P 17.15. $C_7H_{15}O_3P$. Calculated %: P 17.40.

Reaction of sodium diethylphosphite on allyl bromide in the presence of a large quantity of benzene. The benzene solution of sodium diethylphosphite was prepared from 3.8 g sodium, 22.8 g diethylphosphorous acid, and 150 ml benzene. 20 g allyl bromide were taken for the reaction. As a result of performing the reaction we obtained 5.7 g diethylphosphorous acid and 16.3 g allylphosphonic acid ethyl ester with a b.p. of 99-100° (12 mm), n_D^{20} 1.4348, d_4^{20} 1.0368.

Addition of bromine to allylphosphonic acid ethyl ester. To 5.5 g allylphosphonic acid ethyl ester, dissolved in 10 ml carbon tetrachloride, was added, while cooling and with agitation, a solution of 2.5 g bromine in 20 ml carbon tetrachloride. After addition of the entire quantity of bromine, the reaction mixture turned yellow. By distillation of the reaction mixture we separated 2 g of a fraction with b.p. 76-148° (4 mm) and 3.2 g 1,2-dibromo-3-diethylphosphonopropane with a b.p. of 148° (4 mm), n_D^{20} 1.4880, d_4^{20} 1.5730. Found %: P 9.37. $C_7H_{15}O_3PBr_2$. Calculated %: P 9.17.

Addition of diethylphosphorous acid to the ethyl ester of allylphosphonic acid. 6 g allylphosphonic acid ethyl ester and 7 g diethylphosphorous acid were heated in a sealed tube, in the presence of sodium ethylate, at 130-140° for a period of 4 hours. By distillation of the reaction mixture we separated 5.4 g of a substance with a b.p. of 159-160° (2 mm), n_D^{20} 1.4420, d_4^{20} 1.1117.

Preparation of the isomeric chlorobutenes. 3 heavy-walled bottles containing about 400 ml concentrated hydrochloric acid, were cooled in a freezing mixture (−15°) and about 100 g distilled bivinyl added. The bottles were tightly sealed with rubber stoppers and placed on a shaker. Agitation was continued at room temperature for a total period of about 30 hours. The bottles were then opened and the upper layers, containing the chloride, were separated from all of the bottles and combined, washed with a dilute soda solution and with water, then dried over calcium chloride, and distilled through a meter column filled with small glass rings. After several distillations we obtained 62 g 1-chloro-2-butene with a b.p. of 84-85°, n_D^{20} 1.4350 and 80.6 g 3-chloro-1-butene with a b.p. of 64-65°, n_D^{20} 1.4150.

Reaction between sodium diethylphosphite and 1-chloro-2-butene. An ether solution of sodium diethylphosphite was prepared from 6.3 g sodium, 37.8 g diethylphosphorous acid, and 300 ml dry ether. We then added, slowly and with agitation, 25 g 1-chloro-2-butene, after which the reaction mixture was heated on a water bath for 3 hours. At the end of the reaction, sodium chloride was filtered off and washed with ether; the ether in the ether solution was distilled on a water bath after brief drying over calcium chloride, and the residue was distilled under vacuum. We obtained about 5 g of unreacted diethylphosphorous acid and 24 g diethylphosphonobutene-2 with a b.p. of 121.5-122° (19 mm), n_D^{20} 1.4380, d_4^{20} 1.0219, MR_D 49.32. $C_8H_{17}O_3P\ulcorner$. Calculated 49.54. Found %: P 15.84. $C_8H_{17}O_3P$. Calculated %: P 16.14.

Reaction of sodium diethylphosphite on 3-chloro-1-butene. Experiment 1. A benzene solution of sodium diethylphosphite was prepared from 7.4 g sodium, 44.4 g diethylphosphorous acid, and 50 ml benzene. Unreacted small fragments of sodium were mechanically removed from the solution using a long thin needle. We added 30 g 3-chloro-1-butene slowly with stirring to the benzene solution of sodium diethylphosphite which had thus been made completely transparent, after which the reaction mixture was heated for 3 hours on a water bath. Precipitated sodium chloride was then filtered, the benzene evaporated from the filtrate on a water bath, and the residue distilled under vacuum. We obtained 12.8 g diethylphosphorous acid, 18 g 1-diethylphosphonobutene-2 with a b.p. 96-98° (6 mm), n_D^{20} 1.4380 and 6.8 g 1,2-di-(diethylphosphono)-butane with a b.p. of 160.-161° (3 mm), n_D^{20} 1.4420, d_4^{20} 1.1014, MR_D 79.28. Calculated 79.35. Found %: P 19.06. $C_{12}H_{28}O_6P_2$. Calculated %: P 18.78.

Saponification of 1,2-di-(diethylphosphono)-butane with dilute hydrochloric acid at 130-140° gave a thick, pale-yellow colored oil which did not crystallize on standing.

Experiment II. (in the presence of excess diethylphosphorous acid). To a benzene solution of sodium diethylphosphite prepared from 3.7 g sodium, 44.4 g diethylphosphorous acid, and 50 ml benzene, was added 15 g 3-chloro-1-butene. The reaction mixture was heated on a water bath for 3 hours. Sodium chloride was then removed by filtration, the benzene evaporated on a water bath, and the residue distilled under vacuum. Even at the very start of distillation, signs of decomposition of the product were noted; because of this the distillation was stopped and the product worked up in water and benzene. As a result of the last distillation we obtained 18 g diethylphosphorous acid, 8.7 g 1-diethylphosphonobutene-2 having a b.p. of 113-114° (14 mm), n_D^{20} 1.4380, d_4^{20} 1.0221 and 3.6 g of lower-boiling fractions.

Experiment III.(in the presence of a large quantity of benzene). To a benzene solution of sodium diethylphosphite, prepared from 3.7 g sodium, 22.2 g diethylphosphorous acid, and 150 ml benzene, we added 15 g 3-chlorobutene-1. As a result of carrying out the reaction and working up the reaction product, we obtained 7.2 g diethylphosphorous acid, 9.5 g 1-diethylphosphonobutene-2, and about 3 g lower-boiling fractions. Repetition of the experiment with larger quantities of reagents gave analogous results. In this experiment, as in the previous one, 1,2-di-(diethylphosphono)-butane was not observed.

Addition of diethylphosphorous acid to 1-diethylphosphonobutene-2. 7 g diethylphosphorous acid and 5 g 1-diethylphosphonobutene-2 with a small quantity of sodium ethylate were heated in a sealed tube at 130-140° for 3 hours. By distilling the reaction mixture, we obtained 4.8 g 1,2-di-(diethylphosphono)-butane with a b.p. of 159-161° (3 mm), n_D^{20} 1.4420, d_4^{20} 1.1016.

Addition of bromine to 1-diethylphosphonobutene-2. To 6 g 1-diethylphosphonobutene-2 we slowly added, with cooling and stirring, a solution of 2.6 g bromine in 20 ml carbon tetrachloride. The liquid was rapidly decolorized during the reaction; at the end of the addition it developed a stable yellow color. After standing for 24 hours it was vacuum distilled. We obtained 6.7 g 1-diethylphosphono-2,3-dibromobutane with a b.p. of 148-150° (3 mm), n_D^{20} 1.4890, d_4^{20} 1.5427, MR_D 65.86. Calculated 65.54. Found %: P 8.45. $C_8H_{17}O_3PBr_2$. Calculated %: P 8.80.

Oxidation of 1-diethylphosphonobutene-2 by potassium permanganate. 12 g 1-diethylphosphonobutene-2 was dissolved in 400 ml water; 26.4 g finely powdered potassium permanganate was then slowly added to the solution with continuous stirring. The temperature of the reaction mixture was held below 10° by cooling the flask in running water. The manganese dioxide was then filtered off, taken up in boiling water and filtered again. Both filtrates were combined and concentrated to a volume of 30-50ml, treated with hydrochloric acid and steam-distilled. The distillate was neutralized with ammonia and silver acetate was then precipitated from it.

Analysis of the silver salt: 0.5228 g substance: 0.3360 g Ag. Found %: Ag 64.28. $C_2H_3O_2Ag$. Calculated %: Ag 64.61.

SUMMARY

1. The reaction of sodium diethylphosphite with allyl bromide and with isomeric chlorobutenes was studied.

2. It was shown that the presence in the reaction medium of excess diethylphosphorous acid or benzene plays an effective role in the course of these reactions. In their presence the reaction stops at the substitution stage with the formation of allylphosphonic ester and 1-dialkylphosphonobutene-2; in the absence of free diethylphosphorous acid from the reaction medium and in the presence of only the minimum quantity of benzene needed to dissolve the sodium diethylphosphite, sodium diethylphosphite added to the double bond of the allylphosphonic ester with formation of di-dialkylphosphono derivatives.

3. It was shown that the reaction between sodium diethylphosphite and 3-chloro-butene-2 takes place with a complete allyl rearrangement.

4. The addition of diethylphosphorous acid, in the presence of sodium ethylate, to allylphosphinic ester and to 1-diethylphosphonobutene-2 was shown by direct experiments.

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TRIPHENYLBIPHENYLPHOSPHONIUM SALTS

G. V. Medoks and V. F. Andronova

Triphenylaryl- and triphenylalkylphosphonium salts have acquired considerable practical significance in recent times because of application of some of them in analytical chemistry [1] and in the separation of elements which are very similar in properties. These materials are also useful as insecticides [2]. They are also used for protection of woolen materials and furs from damage by moths [3]. There are indications of the possible use of compounds of this type in medicine, and also as plasticizers and as dye-fixing substances. Although several triphenylarylphosphonium salts have been described in the literature, for example the tetraphenylphosphonium [4] and triphenyl- α-naphthylphosphonium [5] salts, nevertheless many other similar compounds, among them the triphenyl-4-biphenylphosphonium salts, had not been prepared up to the present time. In order to prepare quartenary phosphonium salts, in which the phosphorous atom is directly bonded to carbon atoms of the aromatic ring, we may use either the reaction of oxygen on an ether solution of triphenylphosphine together with an organo-magnesium compound, as proposed by Ya. Ya. Dodonov and G. V. Medoks [4], or the reaction of triphenylphosphine with halide substituted aromatic hydrocarbons which takes place with the assistance of catalyst – anhydrous aluminum chloride [6].

We found that cuprous chloride, used as catalyst for analogous reactions, assured a satisfactory reaction course and did not require, in contrast to aluminum chloride, protection from moisture or careful purification in order to avoid side reactions.

We prepared triphenyl-4-biphenylphosphonium bromide, using the above catalyst, from triphenylphosphine and 4-bromo-diphenyl in an 18.3% yield based on triphenylphosphine. A compound of triphenylphosphine and cuprous chloride – $(C_6H_5)_3P \cdot CuCl$ – was also separated from the reaction products. We prepared a solution of the free base, and using this formed triphenyl-4-biphenylphosphonium nitrate, chloride, and sulfate. The formation of a series of other salts is also described. A solution of triphenyl-4-biphenylphosphonium hydroxide did not decompose on boiling, but in the presence of a small quantity of sodium hydroxide boiling led to decomposition of the base according to the equation:

$$[(C_6H_5)_3(C_6H_5C_6H_4)P]OH \longrightarrow (C_6H_5)_3PO + C_6H_5C_6H_5.$$

A similar catalytic activity of alkali has been reported earlier by G. V. Medoks [5].

EXPERIMENTAL

Triphenyl-4-diphenylphosphonium bromide. A mixture, containing 2.6 g triphenylphosphine prepared by the Pfeifer method as modified by Dodonov and Medoks [4], 2.3 g 4-bromo-diphenyl with a m.p. of 89° synthesized according to the procedures of Schmidt and Schultz [7], and 0.5 g cuprous chloride, was heated in a round-bottomed flask on a paraffin bath for 2 hours at 240° and 1 hour at 280°. The reaction product solidified on cooling and was a yellowish glassy mass. It was worked up in ethyl alcohol, and the solution filtered by suction from the separated crystalline precipitate (1.58 g).

The alcoholic solution was evaporated to dryness on a water bath and the residue extracted several times with hot water. The water extracts were combined, filtered, and boiled down. The crystals (0.90 g) with a m.p. of 231° which separated on cooling were recrystallized from water.

0.5894 g substance: 0.1339 g H_2O. Found %: H_2O 22.71. $C_{30}H_{24}BrP \cdot 8H_2O$. Calculated %: H_2O 22.55.

Water of crystallization was completely lost at 110-120°.

0.0423 g and 0.0407 g substance: 8.85 ml and 8.52 ml $AgNO_3$ (T= 0.00163). Found %: Br 16.04 and 16.05. $C_{30}H_{24}BrP$. Calculated %: Br 16.14.

Triphenyl-4-biphenylphosphonium bromide was a colorless substance, readily soluble in water, ethyl alcohol, and chloroform, but insoluble in benzene, benzine, and ethyl ether.

Cuprous chloride addition product with triphenylphosphine. The residue insoluble in alcohol (1.58 g) referred to above was dissolved in chloroform and precipitated by ethyl ether. Colorless crystals, containing chloroform of crystallization. For quantitative iodometric determination of copper, a portion of the substance, free of chloroform of crystallization, was first decomposed with nitric acid (specific gravity 1.4), but for determination of chlorine, by the Moore method, the material was first dissolved in pure chloroform and then decomposed using concentrated ammonia with subsequent heating until excess ammonia was removed.

0.2500 g substance: 17.00 ml $Na_2S_2O_3$ (T = 0.00642). 0.0600 g substance: 17.30 ml $AgNO_3$ (T = 0.00163). Found %: Cu 17.55; Cl 9.81. $C_{18}H_{15}ClPCu$. Calculated %: Cu 17.60; Cl 9.82.

A chloroform solution of this material when treated with a strong solution of ammonia deposits, on vaporization of the solvent, colorless crystals with a m.p. of 79° which were shown to be triphenylphosphine (mixture test). Thus the material which was insoluble in alcohol was an addition product of cuprous chloride and triphenylphosphine.

A small quantity of this substance (1 g) along with 1 g of the initial 4-bromodiphenyl was separated by fractional crystallization of the material (2.85 g) which was insoluble in water on extraction (see above) of triphenyl-4-biphenylphosphonium bromide.

Triphenyl-4-biphenylphosphonium hydroxide and salts. By reaction of an aqueous solution of triphenyl-4-biphenylphosphonium bromide with a suspension of freshly precipitated silver hydroxide in water, a solution of the free base was formed which showed a strong alkaline reaction. This solution was neutralized with the respective acid to yield, after the solution was boiled down and crystallized, the chloride, sulfate, or nitrate; these were colorless crystalline materials, readily soluble in water, ethyl alcohol, and chloroform but insoluble in benzene, benzine, and ethyl ether. The salts were dried in a vacuum dessicator.

0.1032 g substance: 23.69 ml $AgNO_3$ (T = 0.00163). Found %: Cl 7.81. $C_{30}H_{24}ClP$. Calculated %: Cl 7.87. 0.2896 g substance: 0.0699 g $BaSO_4$. Found %: S 3.32. $C_{60}H_{48}P_2SO_4$. Calculated %: S 3.46.

Triphenyl-4-biphenylphosphonium salts dissolved in water reacted with solutions of iodides, thiocyanates, chromates, bichromates, and permanganates to form precipitates which were difficultly soluble in cold water and appreciably soluble in boiling water.

SUMMARY

1. A new catalyst has been proposed for the reaction of triphenylphosphine with halide-substituted aromatics which has several advantages as compared with anhydrous aluminum chloride.

2. Triphenyl-4-biphenylphosphonium salts and a solution of the free base were prepared.

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SYNTHESIS OF ALIPHATIC ORGANO-ELEMENTAL COMPOUNDS BY THE DIAZO METHOD

V. SYNTHESIS OF COMPOUNDS OF ELEMENTS OF THE IV GROUP — ORGANO-LEAD COMPOUNDS

A. Ya. Yakubovich, E. N. Merkulova, S. P. Makarov, and G. I. Gavrilov

Utilization of the extreme reactivity of aliphatic diazo derivatives for preparation of elemento-organo compounds has been limited, until recent times, only to the synthesis of organo-mercury compounds [1]. We were able to show that organic derivatives of P, As, Sb, Bi, Si, and Sn could be prepared by the same method [2].

In this present paper we give the results of our study on the reaction of diazomethane and diazoethane on lead halides. It should be noted that until now only a few organo-lead compounds were known containing a substituted aliphatic radical [3].

Attempts to alkylenate lead chloride by diazomethane were not successful. In tests in ethereal media as well as in other solvents and both in the presence and in the absence of catalysts, although the diazomethane was decomposed no formation of organo-lead compounds was observed. This latter may be explained, naturally, by the fact that lead chloride is practically insoluble in the organic solvents usually used for preparation of solutions of aliphatic diazo compounds. Evidently under these conditions interaction of the reagents is difficult.

It was practically impossible to use a solution of lead tetrachloride because even at temperatures of −15-20°, this material, on the one hand, chlorinated the solvent, and on the other hand, rather rapidly decomposed spontaneously (for example in a CCl_4 medium) with release of chlorine and lead chloride. Alkylenation was also not successful using a stable salt of chloroplumbic acid — $(NH_4)_2PbCl_6$, a derivative of lead tetrachloride, because the solubility of this salt in organic solvents is no greater than that of lead chloride.

Lead tetraacetate, which is readily soluble in benzene, easily reacts with diazomethane, with liberation of nitrogen; naturally organo-lead compounds are not formed in this manner, and the reaction follows the scheme:

$$Pb(OCOCH_3)_4 + CH_2N_2 \longrightarrow CH_2(OCOCH_3)_2 + Pb(OCOCH_3)_2 + N_2.$$

Only with triethylchloro lead and diethyldichloro lead, which are relatively readily soluble in ether, was it possible to observe, on reacting them with diazomethane, formation of the corresponding chloromethyl derivative. However, the alkylenation reaction takes place in this case only in unusual conditions, somewhat different from the conditions employed in other cases. On mixing an ether solution of diazomethane with alkyl lead chloride no reaction was observed either cold or on heating. If copper bronze were added to the mixture, then (at temperatures of 10-15°) gradual decomposition of diazomethane started, during which the precipitate of undissolved lead chloride diminished and the reaction led to formation of chloromethyl lead compounds:

$$CH_2N_2 \xrightarrow{Cu} [CH_2] \xrightarrow{ClPB(C_2H_5)_3} (C_2H_5)_3PbCH_2Cl$$

$$(C_2H_5)_2PbCl_2 \xrightarrow{CH_2} [(C_2H_5)_2PbCl(CH_2Cl)] \xrightarrow{CH_2} (C_2H_5)_2Pb(CH_2Cl)_2.$$

In the reaction described of diazomethane with ethyl lead chloride, in addition to the chloromethyl lead derivative we usually observed formation of a small amount of tetraethyl lead. It is most probable that formation of this takes place as a result of a secondary process of reduction of the initial ethyl lead halide compound by methylene to a lead-alkyl radical, which then disproportionates to form tetraethyl lead. However, formation of tetraethyl lead is also possible as a result of a reaction, which is analogous to one given below for diazoethane. Formation of tetraethyl lead together with the chloromethyl derivative makes purification of the latter considerably more difficult. However, by repeated vacuum distillation it was possible to obtain chloromethyltriethyl and di-(chloromethyl)-diethyl lead in a comparatively pure state. Di-(chloromethyl)-diethyl lead, in contrast to chloromethyltriethyl lead, was a poorly stable compound which decomposed with separation of a precipitate even on storage in the dark.

Diazoethane, like diazomethane, would not react with triethyl lead chloride in absence of catalysts, and the reaction, observed only in presence of copper bronze, led to formation of unstable triethyl-α-chloroethyl lead, which we were not able to separate from the reaction mixture. On removal of solvent (ether) even at temperatures of minus 15° (under vacuum), the product which remained decomposed into lead chloride and tetraethyl lead.

EXPERIMENTAL

1. Preparation of diethyl-di-(chloromethyl)-lead. A mixture of 24 g dichlorodiethyl lead with a small amount of copper bronze (0.1-0.2 g) in 300 ml absolute ether was cooled to 0°. At this temperature and with good stirring we added one half of an ether solution of diazomethane, prepared by taking 2 moles diazomethane per mole of dichlorodiethyl lead plus a 10% excess. The temperature was then raised to 10-15°. During this we observed the release of bubbles of gas, the quantity of dichlorodiethyl lead decreased, and the solution gradually lost its initial yellow color. The solution was then again cooled to 0° and the second portion of diazomethane added.

When the solution was barely yellow and gas evolution ceased, stirring was discontinued, and the reaction mixture allowed to stand overnight. The residue (4.3 g) was then filtered off and the filtrate distilled. After the ether was removed a liquid containing a small amount of precipitate and brown tar remained which was vacuum distilled with a dephlegmator. At 2 mm at a temperature of 86-98° 9.6 g of material came over. After repeated vacuum distillation we separated a colorless mobile liquid with a peculiar odor having a b.p. of 98° at 2 mm; d_4^{20} 1.9890. The material was soluble in absolutely dry organic solvents and insoluble in water.

3.995 mg substance: 3.065 mg AgCl. 0.8380 g substance: 0.6984 g $PbSO_4$. Found %: Pb 56.93; Cl 18.98. $C_6H_{14}PbCl_2$. Calculated %: Pb 56.86; Cl 19.5.

2. Preparation of chloromethyl-triethyl lead. A mixture containing 25 g triethylchloro lead in 260 ml absolute ether together with 0.1-0.2 g copper bronze, was treated with diazomethane (as in experiment I) although the chlorotriethyl lead went into solution completely. Diazomethane was taken on the basis of 1 mole diazomethane (with a 10% excess) per mole of chlorotriethyl lead. Under vacuum distillation at 10 mm and at temperatures of 83-99° a colorless mobile liquid distillate (21.7 g) was obtained. The product thus prepared was a mixture of chloromethyltriethyl lead and tetraethyl lead. Based on its halide content, the mixture contained 73% chloromethyltriethyl lead.

After two or three vacuum distillations with a dephlegmator we were able to separate comparatively pure chloromethyl-triethyl lead with a b.p. of 65.5-66.5° at 3 mm; d_4^{20} 1.7917; n_D^{20} 1.5434. The substance was a mobile liquid with a peculiar odor.

4.313 mg substance: 1.609 mg AgCl. 0.4032 g, 0.3064 g substance: 0.3548 g, 0.2708 g $PbSO_4$. Found %: Pb 60.36, 60.1; Cl 9.23 $C_7H_{17}PbCl$. Calculated %: Pb 60.25; Cl 10.33.

3. Reaction of diazoethane on triethylchloro lead. To a mixture of 10 g triethylchloro lead, 120 ml absolute ether, and 0.15 g copper bronze we added during a period of one hour at 0° (with stirring) a dry solution of 5.2 g diazoethane in 170 ml ether. The temperature was brought up to ambient and a precipitate (3 g) which appeared to be $PbCl_2$ removed from the light green solution by filtration. The ether was distilled under vacuum, during this the remaining oil again separated $PbCl_2$ to the extent of 1 g. Vacuum distillation of the residue gave 5 g of a heavy colorless liquid, whose properties were identical with tetraethyl lead: b.p. 74-75° at 4 mm; n_D^{20} 1.5139; d_{20}^{20} 1.655.

4. Reaction of diazomethane with lead tetraacetate. To a solution of 5 g dry lead tetraacetate in 100 ml absolute benzene we added during a period of one hour at 2° a dry solution of 3.5 g diazomethane in 150 ml benzene while cooling the mixture in ice water. The mixture was allowed to stand at room temperature overnight. It was filtered from the residue, which contained lead diacetate, and the benzene distilled off with a dephlegmator; the residue was vacuum distilled twice. During this we separated methylene diacetate (2 g) with a b.p. of 61° at 3 mm (b.p. according to Butlerov [4] is 170° at 760 mm).

4.620 mg substance: 7.688 mg CO_2; 2.803 mg H_2O. 5.200 mg substance: 8.710 mg CO_2; 2.975 mg H_2O. Found %: C 45.38 C45.68; H 6.79, 6.40. $C_5H_8O_4$. Calculated %: C 45.45; H 6.04.

SUMMARY

The reactions of diazomethane with lead chloride, with a salt of chloroplumbic acid, with lead tetraacetate, with diethyldichloro lead and with triethylchloro lead were studied.

It was found that reaction of organo-lead chlorides with diazomethane takes place only in the presence of

copper bronze catalyst, which promotes the decomposition of the aliphatic diazo compound and leads to formation of the corresponding chloromethyl lead derivative.

Diazoethane reacts with triethylchloro lead in the presence of copper bronze to form unstable triethyl-α-chloroethyl lead, which decomposes into tetraethyl lead and lead chloride.

Lead chloride and ammonium chloroplumbate do not form organo-lead compounds with diazomethane under these conditions.

Lead tetraacetate readily reacts with diazomethane to form methylene diacetate and lead diacetate.

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** See Consultants Bureau translation page 1575.

PHOTOREACTIONS OF ORGANOMETALLIC COMPOUNDS OF MERCURY IN SOLUTION

XI. THE REACTIONS OF β-DINAPHTHYLMERCURY

Yu. A. Oldekop

In one of our earlier papers [1] we studied the behavior of the α-naphtyl-radical, formed by photoreactions of α-dinaphthylmercury in several organic media. It was noted that the α-naphthyl-radical, formed by photolysis of α-naphthylmercury in carbon tetrachloride, did not remove chloride from the latter to form α-chloronaphthalene, but led to redistribution of hydrogen among the naphthyl radicals. It was known to us from the literature [2] that α- and β-dinaphthoylperoxides form, on thermal dissociation in a carbon tetrachloride medium, the corresponding α- and β-chloronaphthalenes. With this in mind it appeared of interest to extend our studies of photoreactions to β-dinaphthylmercury.

We found that photoreaction of β-dinaphthylmercury in carbon tetrachloride gave naphthalene and a small amount of uncrystallizable tarry material, just as in the similar reaction of α-dinaphthylmercury. Thus the photoreaction of β-dinaphthylmercury in carbon tetrachloride differs from thermal dissociation of β-dinaphthoylperoxide in the same solvent.

Among the other products of the photoreaction of β-dinaphthylmercury in carbon tetrachloride, we obtained calomel in a quantitative yield and hexachloroethane. By exposure of β-dinaphthylmercury in chloroform or1,2-dichloroethane to ultra-violet light, a quantitative yield of calomel was obtained. The naphthyl-radical in this case takes hydrogen from the solvent and forms naphthalene. In the experiments with chloroform, in addition, hexachloroethane is found. The formation of calomel in chlorinated organic media on photoreaction of β-dinaphthylmercury in them, should be probably attributed to the subsequent photodissociation of β-naphthylmercury chloride.

From organic media which did not contain halides we selected ethyl cellosolve: the photoreaction of β-dinaphthylmercury took place very slowly in it with the formation of metallic mercury and naphthalene.

The very low solubility of β-dinaphthylmercury in organic compounds markedly reduced the velocity of its photodissociation in comparison with α-dinaphthylmercury. No difference was observed in the behaviour of the β-naphthyl radical formed in comparison with α-naphthyl radicals

EXPERIMENTAL

β-Dinaphthylmercury in carbon tetrachloride. 0.5 g β-dinaphthylmercury in 20 ml carbon tetrachloride were exposed for 120 hrs. At the end of the exposure the precipitate was filtered and dried. It was calomel (blackened by concentrated ammonia): it weighed exactly 0.25 g (quantitative yield). The filtrate was distilled on a water bath. The residue was steam distilled, a white substance with the odor of hexachloroethane and naphthalene solidified in the condenser. We were able, by partial sublimation of this material over concentrated sulfuric acid, to separate pure hexachloroethane with an m.p. of 185° (in a sealed capillary). The melting point of a material known to be hexachloroethane was not depressed by this substance. The remaining portion of the substance was shown to be naphthalene by the melting point of its picrate, m.p. 149° (according to the literature it should be 150°). The residue after steam distillation contained a small amount of tarry products.

β-Dinaphthylmercury in chloroform. 0.5 g β-dinaphthylmercury was exposed in 12 ml chloroform. The exposure lasted for 180 hours. The reaction mass gradually turned a dark brown color. At the end of the exposure, the precipitate was filtered (noticeable traces of mercury in it) and dried. It was shown to be calomel (blackening with concentrated ammonia), its weight was exactly 0.25 g (quantitative yield). Chloroform was evaporated from the filtrate on a water bath. After double distillation, we were able to extract from the distillate some hexachloroethane, m.p. 186° (after sublimation above concentrated sulfuric acid). This material did not depress the melting point of a known pure preparation of hexachloroethane. The residue from the first distillation was steam distilled. A white crystalline substance solidified in the condenser; this was shown to be naphthalene, its weight was 0.1 g. The melting point of this material was 80° (from alcohol). The material did not depress the melting point of pure naphthalene.

β-Dinaphthylmercury and 1,2-dichloroethane. 0.5 g β-dinaphthylmercury in 10 ml 1,2-dichloroethane was exposed for 180 hours. After exposure traces of mercury were noted. The precipitate was filtered, it weighed exactly 0.25 g. It was calomel (blackening with concentrated ammonia). From the filtrate before steam distillation we extracted 0.1 g naphthalene, m.p. 79°. This material did not depress the melting point of known naphthalene.

β-Dinaphthylmercury and ethylcellosolve. 0.5 g β-dinaphthylmercury in 20 ml ethylcellosolve was exposed for 400 hours. At the end of the exposure the precipitate was filtered. 0.18 g metallic mercury was found in it (82% of theoretical), together with unreacted β-dinaphthylmercury; m.p. 237° (from dichloroethane), weight 0.08 g (16% of initial). The filtrate was diluted with water, a white floc separated which was filtered and recrystallized from alcohol; its weight was 0.15 g, m.p. 80°. This material did not depress the melting point of a pure sample of naphthalene.

All the experiments on exposure to ultra-violet light were performed in sealed long narrow quartz tubes with an internal diameter of 8 mm. A PRK-2 lamp was used as the light source.

SUMMARY

1. β-Dinaphthylmercury reacts with carbon tetrachloride when exposed to ultra-violet light with formation of calomel, naphthalene, hexachloroethane, and tarry materials.

2. Photoreaction of β-dinaphthylmercury in chloroform gives calomel, naphthalene, and hexachloroethane. In the analogous reaction of β-dinaphthylmercury in 1,2-dichloroethane, calomel and naphthalene form.

3. In photoreaction of β-dinaphthylmercury in ethylcellosolve, metallic mercury and naphthalene were formed.

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REDUCTION OF PYRIDINE AND ITS HOMOLOGS ON THE DROPPING MERCURY ELECTRODE

A. G. Pozdeeva and E. M. Gepshtein

We selected, as subjects for study, pyridine, β- and γ-picolines, and 2,6-lutidine. References exist in the literature [1-3] on the reduction of pyridine on the dropping mercury electrode; the homologs of pyridine to all appearances have not been studied by anyone up to the present time.

Preparation of products for study. Many methods are given in the literature, in the form of patents for the most part, for separation of the mentioned pyridine homologs from their corresponding fractions. However, it is difficult in practice to prepare pure β- and γ-picoline and 2,6-lutidine from their fractions because of the lack of specific procedures and methods for separation of these products.

In the present research, we utilized several suggestions for their preparation from the literature [4-7], but we defined the separate steps of the process more accurately, and recommend the scheme given here for separation of pyridine homologs from the β-picoline fraction.

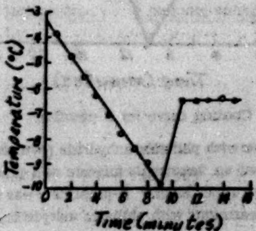


Figure 1. Cooling Curve for 2,6-lutidine.

Preparation of 2,6-Lutidine. To 238 g of a narrow boiling β-picoline fraction heated in a flask with a reflux condenser on a boiling water bath, was added a hot saturated solution of 200 g urea in 108 ml water. The reaction mixture was heated for a period of one hour on a boiling water bath with agitation. The solution was then slowly cooled over a 6 hour period. The crystals of 2,6-lutidine-urea which separated were suction filtered on a Buchner funnel. The filtrate was set aside for preparation of β- and γ-picolines. The crystals of the 2,6-lutidine-urea complex were airdried for a 10-15 hour period and then decomposed by water (we used 1 liter of water for 200 g of the complex). 2,6-Lutidine was in the water layer after decomposition of the complex, and was extracted from it by ether. The ether was then vaporized on the water bath, and the residue in the flask was raw 2,6-lutidine; it was thoroughly dried with anhydrous caustic. After two precipitations of 2,6-lutidine by urea, as described above, the product had a crystallization temperature of minus 23°. The 2,6-lutidine was subsequently fractionally crystallized 7 times, as a result of which we were able to raise the crystallization temperature of our sample of 2,6-lutidine to minus 8.4°. This product was thoroughly dried over caustic and distilled from a flask with a small nozzle. The one-degree fraction which was separated solidified at minus 6.5°. The purity of the prepared product was determined by a thermographic method, i.e., by the curve of freezing point temperatures versus time (Figure 1).

Preparation of γ-picoline. The fraction which was freed of 2,6-lutidine was treated with a solution of calcium chloride. To 356g of the fraction, heated to 60-70° on a water bath, we added in small portions with stirring a hot solution of 570 g crystalline calcium chloride dissolved in 36 ml water. After addition of the entire calcium chloride solution, the reaction mixture was stirred for 10 minutes and the solution then slowly cooled over a 5-6 hour period, after which the crystals of the complex compound of γ-picoline and calcium chloride which were obtained were filtered by suction on a Buchner funnel and dried on a watch glass in a slightly warm drying oven. The filtrate was reserved for preparation of β-picoline. The dry crystals of the complex were decomposed by water at room temperature, and the base extracted from the water solution using ether; the ether was then evaporated on a water bath leaving γ-picoline as a residue in the flask which was then precipitated a second time with calcium chloride.

After two precipitations of γ-picoline using a solution of calcium chloride, we obtained 87 g raw γ-picoline.

This product was distilled from a flask with a 48-hook dephlegmator (effectively 1-2 theoretical plates). The fraction boiling at 143.5° (50.5 g) was pure γ-picoline and solidified at 2.6° (Figure 2).

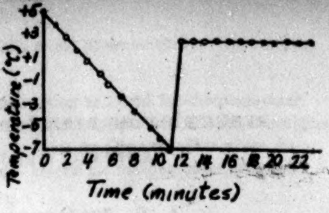


Figure 2. Cooling Curve for γ-picoline

Preparation of β-picoline. The fraction which had been freed from 2,6-lutidine and γ-picoline was polymerized using elemental sulfur. To 108 g of the fraction which contained β-picoline with a small admixture of γ-picoline, was added 33 g sulfur and 1.1 g zinc chloride. The reaction mixture was heated in a flask fitted with a reflux condenser on a hot plate for 40 hours. An additional 20 g sulfur and 1 g zinc chloride were added to the cooled reaction mixture, and the mixture again heated to boiling for a period of 24 hours. The unreacted β-picoline was then removed by steam distillation. The distillate was salted out using solid caustic, the β-picoline was separated from the aqueous layer and thoroughly dried with anhydrous caustic. The product so prepared was distilled in a flask fitted with a 48-hook dephlegmator. The fraction boiling within the limits 142.4-142.6° (35 g) was β-picoline, which was then purified by two treatments with phthalic anhydride. Thus, to 26.5 g β-picoline we added 6.7 g acetic anhydride and 6.7 g phthalic anhydride.

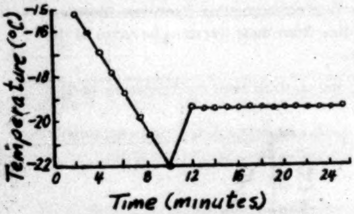


Figure 3. Cooling curve for β-picoline

The mixture was heated in a flask with a reflux condenser for 4 hours on a water bath. The contents of the flask were then poured into 100 ml water and the solution made strongly alkaline to litmus with 50% NaOH solution. The solution was then filtered, and a rather small quantity of dark brown colored precipitate was found on the filter—this was a condensation product of γ-picoline and 2,6-lutidine with phthalic anhydride (pyrophthalones). From the filtrate, which contained a solution of β-picoline, was distilled an azeotropic mixture of β-picoline and water at 97-98°. After the distillate was treated with solid caustic, the upper layer — β-picoline — was separated from water and dried with anhydrous caustic. After two purification treatments with phthalic anhydride, we obtained β-picoline which solidified at minus 19.4° (Figure 3).

Preparation of pyridine. Pyridine was obtained from the pyridine fraction by repeated fractionation in a column. The characteristics of the product obtained (as compared with literature data) may be seen in the table.

As may be seen from the tables the products prepared were pure pyridine, 2,6-lutidine, β- and γ-picoline. Slight differences in the freezing points, amounting to tenths of a degree, may be explained by the difficulty of determining the melting points of these products because they are all strongly hygroscopic materials.

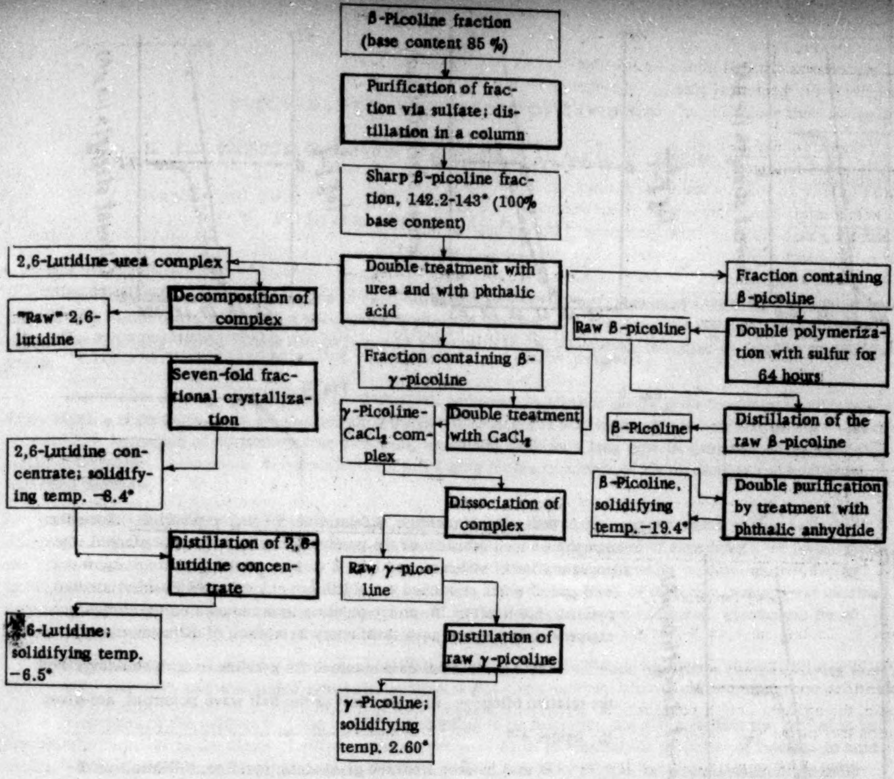
EXPERIMENTAL

In order to prepare the polarograms, we used a visual polarograph manufactured by UFAN in 1947 (Sverdlovsk) and a galvanometer of the Leningrad Institute for Construction of Physics Equipment with a current sensitivity of 2.77×10^{-9} A mm/m. All measurements were made at a temperature of 25 ± 0.1°. A saturated calomel electrode was used as the anode and its potential was taken as zero. We used in this work a capillary with a dropping period of 2.4 seconds. For reduction studies on the pyridines, we took them as solutions in 50% ethyl alcohol. An 0.1 N solution of LiCl in 50% alcohol was used as an electrolyte. In order to remove atmospheric oxygen from the solution under test, we passed hydrogen through the solution for a 15-20 minute period. The half wave potential was determined by the wave equation (1):

$$E = E_{1/2} - \frac{0.0591}{n} \log \frac{i}{I-i}, \qquad (1)$$

where i is the current strength at voltage E, and I is the diffusion current.

Graphically, this equation gives a straight line with slope 0.0591/n when $\log \frac{i}{I-i}$ is plotted as a function of E. The point on the straight line where $\log \frac{i}{I-i} = 0$, i.e., where $\frac{i}{I-i} = 1$ and $i = \frac{1}{2} I$, corresponds to the half wave potential, as may be seen from the wave equation. We determined the value of the half wave potential in this manner.


β-Picoline fraction (base content 85 %)
Purification of fraction via sulfate; distillation in a column
Sharp β-picoline fraction, 142.2-143° (100% base content)
2,6-Lutidine-urea complex
Double treatment with urea and with phthalic acid
Fraction containing β-picoline
Decomposition of complex
"Raw" 2,6-lutidine
Raw β-picoline
Double polymerization with sulfur for 64 hours
Fraction containing β-γ-picoline
Seven-fold fractional crystallization
γ-Picoline-CaCl₂ complex
Double treatment with CaCl₂
β-Picoline
Distillation of the raw β-picoline
2,6-Lutidine concentrate; solidifying temp. −8.4°
β-Picoline, solidifying temp. −19.4°
Double purification by treatment with phthalic anhydride
Dissociation of complex
Distillation of 2,6-lutidine concentrate
Raw γ-picoline
[illegible]6-Lutidine; solidifying temp. −6.5°
Distillation of raw γ-picoline
γ-Picoline; solidifying temp. 2.60°

Constant	Pyridine		2,6-Lutidine		γ-Picoline		β-Picoline		Literature ref.
	Our data	Literature values	Our data	Literature values	Our data	Literature values	Our data	Literature values	
Density	0.9780 (25°)	0.978(25°) 0.981	0.9241 (15°)	0.915(16°) 0.932(25°)	0.9572 (20°)	0.957 (20°)	0.9510 (20°)	0.952(20°)	[7-11]
Boiling point	115.3°	116° 115.2 115.3 115.4	144.4°	142.8° 144.2 144.4 144.7	144.9°	143.1° 144.6	144.0°	142-143° 143.8 143.9 144.0	
Index of Refraction	1.5010 (20°)	1.5091	1.5000 (16°)	1.4996 (16°)	1.5050 (20°)	1.5052 (20°)	0.5050 (20°)	1.5040 (20°) 1.5043 (24°)	
Melting point	−41°	−42°	−6.5°	−6° −6.3 −6.5	+2.6°	+ 3° + 3.5 + 3.8	−19.4°	−17.9° −18.3 −18.7	

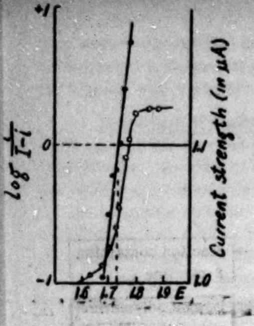


Fig. 4.

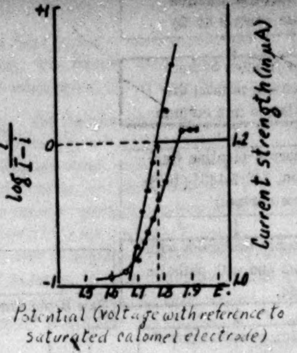


Fig. 5

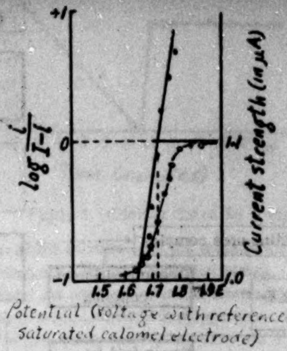


Fig. 6

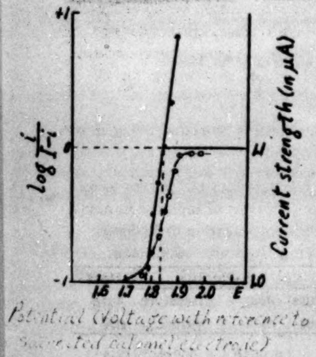


Fig. 7

Reduction of pyridine, 2,6-lutidine, β- and γ-picoline. For polarography we used solutions of the pyridine bases in 50% ethyl alcohol, the concentration of which ranged from 5 to 10 m.moles per liter. Against a background which contained 0.1 N lithium chloride in 50% ethyl alcohol, pyridine, 2,6-lutidine, β- and γ-picoline were reduced on the dropping mercury electrode and gave satisfactory expression of diffusion current.

The experimental data obtained for pyridine and its homologs, both the relation of $\log \frac{i}{I-i}$ with E as well as the half wave potential, are given in figures 4-7.

As may be seen from the given data, pyridine, 2,6-lutidine, β- and γ-picoline are polarographically active materials, i.e., they are reduced by a dropping mercury electrode. γ-Picoline is the most difficult to reduce ($E_{1/2}$ = −1.83V), β-picoline is the easiest ($E_{1/2}$ = −1.72 V); 2,6-lutidine has a half wave potential of minus 1.78 V, and pyridine has one of minus 1.73 V—all relative to the saturated calomel electrode.

SUMMARY

1. A study has been made of the reduction of pyridine and several of its homologs by the dropping mercury electrode.
2. The half wave potentials for pyridine, 2,6-lutidine, β- and γ-picoline have been determined.
3. A scheme for separation of 2,6-lutidine and β- and γ-picoline from an industrial β-picoline fraction is proposed.

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ELECTROLYTIC REDUCTION OF LEPIDINE

II. ELECTROLYTIC REDUCTION OF LEPIDINE IN AN ALKALINE MEDIUM

V. V. Levchenko and A. A. Zats

By chemical reduction of lepidine in an alkaline medium, Williams [1] obtained a yellowish oil, which on boiling with dilute nitric acid gave a red colored crystalline product. Williams regarded this product as the nitrate of lepidine $C_{20}H_{18}N_2 \cdot HNO_3$. There are no literature references on the electrolytic reduction of lepidine in alkaline media.

Our studies showed, that lepidine on electrolytic reduction in alkaline media gives the dimer of dihydrolepidine, which was prepared by us by electrolytic reduction of lepidine in acid media [2]; in addition we were able to establish the formation of dihydrolepidine monomer, which was stable for a long time in a mixture of lepidine and tetrahydrolepidine. Monomeric dihydrolepidine forms during further treatment of the electrolyte two additional oxidation products.

Electrolytic reduction of lepidine was performed in an alkaline alcohol-water solution using a cellophane diaphragm. We used a mercury cathode and a platinum anode. In a large number of experiments we investigated the effect of many factors on the process of electrolytic reduction of lepidine, namely: voltage, current density, temperature, length of electrolysis, and alkali concentration. The highest yield of reduction products was obtained on a renewed mercury cathode using a current density of 26.6 amperes per square decimeter, electrolysis for 45 minutes, temperature 16-19°, as was observed in studies by Levchenko [3,4].

By electrolytic reduction of lepidine in alkaline media, we obtained three crystalline products having m.p.'s of 279, 236, and 203°, and also liquid tetrahydrolepidine.

Properties of the product melting at 279°. According to its properties, the given product was proven to be completely identical to the dimer of dihydrolepidine, prepared by us by electrolytic reduction of lepidine in acid media. This was confirmed by ultimate analysis of the product and of its picrate, by determination of its molecular weight (Rast method), and also by determination of the melting point of samples mixed with dihydrolepidine dimer (which had been prepared by electrolytic reduction of lepidine in acid media) which was not depressed. Dihydrolepidine dimer was not formed if the electrolysis was performed at high temperatures.

The dimer of dihydrolepidine was converted into tetrahydrolepidine by chemical reduction by boiling for several hours in concentrated hydrochloric acid with tin.

Properties of the product melting at 236°. The material did not dissolve in alkali and was readily soluble in acids with formation of salts. Ether and ligroin were the organic solvents in which it was not soluble; it dissolved readily in chloroform when cold, and in alcohol, benzene, toluene, and xylene when heated. It did not give a color with a solution of potassium bichromate in sulfuric acid. It was not affected by electrolytic reduction in acid media; chemical reduction by boiling for 5 hours in concentrated hydrochloric acid and tin led to tetrahydrolepidine. Ultimate analysis and determination of the molecular weight gave its elemental content which corresponds to the formula $(C_{10}H_{10}N)_2O$.

This product formed a picrate melting at 242°. Ultimate analysis of the picrate confirmed the formula given above for dihydrolepidine oxide, prepared according to the equation:

$$2C_{10}H_{11}ON-H_2O=(C_{10}H_{10}N)_2O.$$

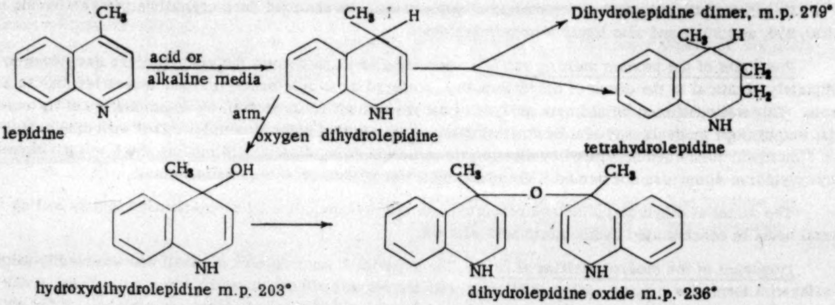
Properties of the product melting at 203°. The crystalline product with an m.p. of 203° which was obtained from the distillation flask after steam distillation of lepidine and tetrahydrolepidine sharply differed from the product with an m.p. of 236°; it was appreciably soluble in water, and was soluble not only in acids but also in alkalies. The aqueous solution was slightly fluorescent. It gave with potassium hydroxide a potassium salt which was readily hydrolyzed. The potassium salt was readily decomposed by carbonic acid. With hydrochloric acid the product formed a hydrochloride, the latter reacted with platinum chloride to form a double platinate having the composition of $[C_{10}H_{11}ON \cdot HCl]_2 \cdot PtCl_4$, which was confirmed by determination of the platinum content of this salt. It formed a derivative with benzoyl chloride which melted at 233°; its nitrosoamine had an m.p. of 235°, and it formed a methyl derivative (m.p. 185°). It did not give a color with a solution of potassium bichromate in sulfuric acid. We did not electrolytically reduce this product further in alkaline medium; in acid medium it was reduced to tetrahydrolepidine with yields ranging from 25 to 33% depending on length of electrolysis. Ultimate analysis and determination of its molecular weight gave its elemental content, which corresponded to the formula of hydroxydihydrolepidine: $C_{10}H_{11}ON$.

Hydroxydihydrolepidine formed a picrate, m.p 223-224°, the elemental analysis of which confirmed the formula given above for hydroxydihydrolepidine.

Hydroxydihydrolepidine $C_{10}H_{11}ON$ displays both basic and acid properties, and the structural formula of γ-hydroxydihydrolepidine may be tentatively ascribed to it, because α-hydroxydihydrolepidine which was prepared by Knorr and Klotz [5] by chemical reduction of α-hydroxylepidine has properties which differ from the product prepared by us.

Consequently, when the ether extract of the products from electrolytic reduction of lepidine in alkaline medium was stored in an open vessel in the air, polymerization of dihydrolepidine into the dimer occurred as well as formation of two more dihydrolepidine oxidation products. This indicates the presence, in the ethereal extract, of dihydrolepidine monomer, which is readily oxidized by atmospheric oxygen. This material is stable with time only in alkaline media; this is apparent because we were not able to obtain its oxidation products from the products of reduction of lepidine in acid media, despite our many attempts.

By action of more severe oxidizing agents (such as hydrogen peroxide) on the ether extract from alkaline electrolysis, it was not possible to obtain hydroxydihydrolepidine because under these conditions oxidation goes farther and leads to formation of tarry materials It was also not possible to separate the monomeric dihydrolepidine from the tetrahydrolepidine and residual unreacted lepidine which accompanied it despite many attempts to achieve this by distillation of the mixture under vacuum, fractional crystallization of their hydrochlorides prepared by treatment with hydrogen chloride, and others. The direction of the processes, as established by us, which take place during reduction of lepidine, may be presented in the form of the following scheme:



EXPERIMENTAL

Performance of the electrolytic reduction of lepidine in an alkaline medium. We used 1 ml lepidine (1.08 g) per stage of electrolytic reduction. This quantity of lepidine was dissolved in an electroyte prepared from 25 ml 18% potassium hydroxide solution and 25 ml 96° ethyl alcohol. The prepared transparent solution was used as a cathode liquid, mercury was the cathode. As an anode region we used a cylindrical glass vessel separated from the cathode region by two layers of cellophane. An 18% solution of potassium hydroxide (20 ml) was poured into the inside of the vessel. A platinum anode was used. Electrolysis was continued for 45 mintues. The current density was 26.6 A/dm^2 at a voltage of 9-11 V. The temperature during electrolysis was held at level not higher than 19° by cooling.

Separation of reaction products. 10.8 g lepidine was reduced under the given conditions in ten portions. At the end of the electrolysis, the cathode liquid (which was very turbid with drops of yellow oily product) was placed in a separatory funnel and diluted to 100 ml with water used for washing the electrolyzer. An ether extract, which gradually changed color in air from light yellow to dark red, was made of the cathode liquid. All the ether extracts were combined together and were permitted to stand in an open vessel in the air for a 48 hour period. During evaporation of ether from the extract, the formation of a crystalline product was observed. When all of the ether had evaporated, the crystalline product was filtered; the yield of this was 1.8 g (16.4%), it was recrystallized several times from boiling toluene; m.p. 279°. Careful study of the properties of this material, together with the data of its ultimate analysis, showed that it was the dimer of dihydrolepidine.

The filtrate, after separation of the dimer of dihydrolepidine, was steam distilled for separation of unreacted lepidine and tetrahydrolepidine. Distillation was continued until the distillate no longer developed a red color with a sulfuric acid solution of potassium dichromate (test for tetrahydrolepidine). The distillate contained an oily product, which was extracted by ether. The ether extract was dried over anhydrous sodium sulfate, and after evaporation of the ether we obtained a yellow oil which was a mixture of unreacted lepidine and tetrahydrolepidine. 4.6 g of this mixture was obtained (42.6%).

After lepidine and tetrahydrolepidine were distilled with steam, a tarry dark brown material was left in the distillation flask; it was filtered from the liquid and on cooling solidified as a solid brittle mass, weight 3.9 g (37%). The filtrate was a light yellow liquid. The tarry product was crushed and worked up in ether. The ether dissolved the tarry material; the undissolved crystalline residue was filtered and dried; dark grey color, weight 0.6 g (5.2%). After repeated recrystallization from toluene we obtained a crystalline product with m.p. 236°.

13.680 mg substance: 39.490 mg CO_2; 8.215 mg H_2O. 11.970 mg substance: 34.512 mg CO_2; 7.273 mg H_2O. 15 540 mg substance: 1.273 ml N_2 (26°, 743 mm). 13.700 mg substance: 1.145 ml N_2, (26.5°, 744 mm). 0.0073 g substance; 0.0854 g camphor: Δt 11.6°. 0.0049 g substance; 0.0678 g camphor: Δt 9.7°. Found %: C 78.79, 78.70; H 6.72, 6.80; N 9.18, 9.32; M 294.7, 298.0 $(C_{10}H_{10}N)_2O$. Calculated %: C 78.91; H 6.61; N 9.20; M 304.4.

Analysis of the picrate. 3.446 mg substance: 0.400 ml N_2 (19°, 742.4 mm). 4.299 mg substance: 0.500 ml N_2 (21°, 742.6 mm). Found %: N 13.25, 13.19. $(C_{10}H_{10}N)_2O \cdot C_6H_2(OH)(NO_2)_3$. Calculated %: N 13.12.

It follows from the above that the material obtained was dihydrolepidine oxide.

From the filtrate obtained after separating the tarry product from the distillation flask, we separated by cooling a yellow colored crystalline substance which weighed 0.62 g (5%) after drying. After repeated recrystallization from boiling toluene a crystalline product with m.p. 203° was obtained.

TABLE 1

Quantity of starting material per 50 ml electrolyte (grams)	Temperature	Current density (Amperes/ Sq. dm.)	Dihydrolepidine yield, based on matial (% of theoretical)
3.24	19°	8.8	5.58
3.24	19	17.7	6.16
3.24	19	26.6	6.34
3.24	19	35.4	11.71
3.24	19	42.5	7.54

3.559 mg substance: 9.735 mg CO_2; 2.241 mg H_2O.
3.982 mg substance: 10.900 mg CO_2; 2.530 mg H_2O.
17.020 mg substance: 1.340 ml N_2 (28.5°, 739 mm).
15.800 mg substance: 1.230 ml N_2 (22°, 741 mm).
0.0063 g substance; 0.0692 g camphor: Δt 22.8°.
0.0036 g substance; 0.0720 g camphor: Δt 12.9°.
Found %: C 74.66, 74.72; H 7.04, 7.11; N 8.66, 8.84; M 159.7, 155.4. $C_{10}H_{11}ON$. Calculated %: C 74.51; H 6.88, N 8.69; M 161.2.

It follows from the above that the product obtained was hydroxydihydrolepidine. This is also indicated by analysis of the picrate.

4.614 mg substance: 0.593 ml N_2 (25°, 735 mm). 4.350 mg substance: 0.555 ml N_2 (26°, 734 mm). Found %: N 14.22, 14.44. $C_{10}H_{11}ON \cdot C_6H_2(OH)(NO_2)_3$. Calculated %: N 14.35.

In the tables below are given the yields of products of reduction of lepidine (dihydrolepidine dimer, dihydrolepidine oxide, and hydroxydihydrolepidine), recalculated to dihydrolepidine, in relation to the different conditions of electrolysis. In each case the average of 3-5 experiments is given.

Effect of current density on yield of dihydrolepidine. (length of electrolysis 23 minutes, quiescent mercury). The test results are given in Table 1.

It follows from the results obtained that the yield of dihydrolepidine increases with increase in current density to an optimum value at 35.4 A/dm^2; with further increase in current density the yield of dihydrolepidine falls and that of tetrahydrolepidine increases.

Effect of temperature on yield of dihydrolepidine. (length of electrolysis 45 minutes, 3.24 g lepidine in 50 ml electrolyte, current density 35.4 A/dm^2).

The test results are given in Table 2.

TABLE 2

Temperature	Dihydrolepidine yield, based on material (% of theoretical)
19°	12.01
35	6.18
62	3.86

Increase in temperature significantly decreases the yield of dihydrolepidine; at higher temperatures the reduction of lepidine leads to tetrahydrolepidine.

Effect of length of electrolysis on dihydrolepidine yield. (3.24 g lepidine in 50 ml electrolyte, current density 35.4 A/dm^2, temperature 19°). Test results are given in Table 3.

TABLE 3

Length of electrolysis (min.)	Dihydrolepidine yield	
	Based on material (% of theoretical)	Based on current, (%)
10	6.42	11.8
23	11.71	8.72
45	12.01	4.87
90	13.44	1.49
180	17.60	1.79

With increase in the length of electrolysis the dihydrolepidine yield, based on material, increases.

Effect of concentration of starting materials on dihydrolepidine yield. (Length of electrolysis 23 minutes, current density 26.6 A/dm^2, temperature 19°). The test results are given in Table 4.

TABLE 4

Quantity of lepidine (g per 50 ml electrolyte)	Dihydrolepidine yield, based on current(%)
0.54	3.51
1.08	3.84
1.52	5.33
3.24	6.39
6.48	6.76

With increasing lepidine concentration in the electrolyte, the yield of dihydrolepidine based on current increases.

Effect of manner (velocity) of mercury renewal on dihydrolepidine yield. The test results are given in Table 5.

TABLE 5

Cathode	Dihydrolepidine yield, based on material (% of theoretical)		
	Length of electrolysis, 45 minutes, current density 35.4 A/dm^2 temp. 16°	Length of electrolysis 45 minutes, current density 26.6 A/dm^2, temp. 18°	
		1.08 g lepidine taken per 50 ml electrolyte	1.08 g lepidine taken per 100 ml electrolyte
Unrenewed mercury cathode	7.21	12.69	24.01
Renewed mercury cathode	11.57	26.56	24.14
Undulating mercury cathode	14.75	0	25.93

Change in manner (velocity) of mercury renewal significantly increases dihydrolepidine yield.

SUMMARY

1. It has been shown by our studies that electrolytic reduction of lepidine in alkaline medium leads to formation of dihydrolepidine in the form of its monomer $C_{10}H_{11}N$ which is retained in solution, and that on steam distillation it may be obtained in a mixture with tetrahydrolepidine $C_{10}H_{13}N$ together with unreduced lepidine $C_{10}H_9N$.

2. Dihydrolepidine monomer, which exists in the cathode liquid mixed with tetrahydrolepidine and lepidine, gave at low temperature the dimer of dihydrolepidine, and under action of atmospheric oxygen was oxidized to form two crystalline products: dihydrolepidine oxide $(C_{10}H_{10}N)_2O$ and hydroxydihydrolepidine $C_{10}H_{11}ON$, to which we ascribe the formula of γ-hydroxydihydrolepidine.

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* See Consultants Bureau translation page 1301.

** See Consultants Bureau translation page 867.

CHEMICAL REDUCTION OF LEPIDINE

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Methods for chemical reduction of quinoline and ethylpyridine by boiling with tin and hydrochloric acid and also by treatment with sodium in alcoholic media, were first developed by Vyshnegradsky [1,2]. These methods have not lost their value to the present time and find wide application for reduction of these and other materials. Knorr and Klotz [3], who performed the chemical reduction of lepidine in acid medium by boiling with tin in hydrochloric acid, obtained tetrahydrolepidine. Metallic sodium in an alcohol solution, according to the findings of Mikhailov [4], readily reduced lepidine to tetrahydrolepidine. Williams [5], by action on lepidine of sodium amalgam containing 10% sodium, obtained a yellow oil which when boiled with nitric acid was converted into a crystalline product with a red color whose composition was $C_{20}H_{18}N_2 \cdot HNO_3$; Williams called this material lepidine nitrate.

The purpose of the present investigation was the determination of similarities or differences between chemical reduction of lepidine and its electrolytic reduction, as a result of which we [6,7] had obtained products not previously described in the literature: dihydrolepidine dimer, dihydrolepidine oxide, and γ-hydroxydihydrolepidine.

By chemical reduction of lepidine by the method of Vyshnegradsky using sodium in alcoholic medium, we obtained tetrahydrolepidine. By chemical reduction of lepidine using sodium or potassium amalgam we separated exactly the same products as in electrolytic reduction of lepidine in alkaline medium. By performing the chemical reduction of lepidine by boiling it with tin in hydrochloric acid, we were able to prepare, in addition to tetrahydrolepidine, a crystalline product which appeared to be another isomer of dihydrolepidine, other than the one obtained by us on electrolytic reduction of lepidine in acid or alkaline medium. The yield of raw product was about 1%. After recrystallization from ligroin we obtained a crystalline white material; small rods, m.p. 187°.

Properties of the product obtained having an m.p. of 187°. The material was insoluble in alkali, readily soluble in hydrochloric acid; on neutralization with alkali it separated unchanged. It was readily soluble in toluene and chloroform when cold; in ligroin and alcohol it was slightly soluble cold and readily soluble on heating. It could be easily purified by recrystallization from the two latter solvents. Like tetrahydrolepidine, it gave an intense color with a solution of potassium dichromate in sulfuric acid. Ultimate analysis gave its elemental composition, which corresponds to the formula $C_{10}H_{11}N$; determination of its molecular weight (by Rast, and by cryoscopic method) showed it to be a dimer of dihydrolepidine $(C_{10}H_{11}N)_2$. This dimer differs sharply from the dimer of dihydrolepidine obtained by us on electrolytic reduction of lepidine in acid medium. A mixture test of both dimers gave significant depression in determination of the melting point.

EXPERIMENTAL

a) Reduction of lepidine by metallic sodium in an alcohol solution. 1 ml (1.08 g) lepidine was dissolved in 10 ml ethyl alcohol, and the solution brought to a boil on a water bath. Metallic sodium, in small pieces, was added to the boiling solution until reaction with alcohol ceased. The solution thickened considerably; on dilution with water no change took place; the solution had a strong alkaline reaction; tests for presence of tetrahydrolepidine with a solution of potassium dichromate in sulfuric acid gave an intense coloration. The solution was extracted with ether, and the extract allowed to stand for evaporation of the ether. The ether extract was barely yellowish in color; the oily material remaining after the ether was evaporated was steam distilled. The presence of tetrahydrolepidine was demonstrated in the products of distillation; the distillate was extracted with ether, and the extract dried over anhydrous sodium sulfate. After evaporation of the ether on a water bath we obtained 0.85 g tetrahydrolepidine, which was identified by its benzoyl derivative. A small amount of yellow colored tarry material formed in the distillation flask. The dry weight of this tar was 0.13 g. The tarry product was readily soluble in ether and alcohol, attempts to separate some crystalline material from the tar gave negative results. We were also unable to obtain any product from the liquid which remained in the distillation flask. Thus, reduction of lepidine by the Vyshnegradsky procedure gave tetrahydrolepidine.

b) Reduction of lepidine by potassium and sodium amalgams. For the chemical reduction, we took 3 ml (3.24 g) lepidine and dissolved it in 50 ml of a mixture of 25 ml alcohol and 25 ml 18% potassium hydroxide solution. The prepared solution was poured onto a 1.5% potassium amalgam, 50 ml volume; reduction continued for 45 minutes with energetic stirring. The temperature was held at a level below 18° by cooling. After a lapse of 45 minutes the mercury was separated from the liquid, which contained droplets of a yellow oily product, using a separatory funnel. The solution was extracted by ether and the extract worked up in the same manner as had been used in the electrolytic reduction of lepidine in alkaline medium [7]. As a result we obtained the following quantities of products: dihydrolepidine dimer 0.22 g (6.7%), dihydrolepidine oxide 0.41 g (11.8%), hydroxydihydrolepidine 0.14 g (4.2%), tarry product from the distillation flask 1.39 g (43%), and a mixture of lepidine and tetrahydrolepidine 1.1 g (33.9%). The total yield of the first three products, recalculated to dihydrolepidine, amounted to 22.4% by weight of the theoretical. Increase in length of reduction to 3.5 hours increased the yield of products, recalculated to dihydrolepidine, to 32.7%. Reduction of lepidine by sodium amalgam took place in a similar manner. Performing these experiments on chemical reduction of lepidine by potassium and sodium amalgam, show that there was no difference between chemical reduction and electrolytic reduction of lepidine in alkaline medium using a quiescent mercury cathode.

c) Chemical reduction of lepidine in acid medium. 3 ml (3.24 g) lepidine was dissolved in 50 ml concentrated hydrochloric acid; 15 g granular tin was added to the prepared solution, and the entire mixture boiled on a sand bath for 8 hours in a round-bottom flask fitted with a reflux condenser. At the end of the stated time, the hot solution was decanted from the very small quantity of unreacted tin which remained. On cooling the solution, white and yellow colored crystals separated, which were evidently a mixture of double tin salts of lepidine hydrochloride and the products of its reduction. The crystals which separated were suction filtered and washed with weakly acidified ice water. The double salts were treated with a concentrated solution of potassium hydroxide; the dark brown colored solution thus obtained was steam distilled. The first portions of the distillate gave an intense color with a solution of potassium dichromate in sulfuric acid (test for tetrahydrolepidine); steam distillation was continued until reaction with potassium dichromate ceased. The distillate was extracted by ether. The ether extract was dried over anhydrous sodium sulfate. The ether was distilled on a water bath, and as a residue we obtained an oily product which was a mixture of unreacted lepidine and tetrahydrolepidine. 2.25 g (69.4%) of this mixture was obtained. The liquid which remained in the distillation flask was filtered. A dirty brown colored residue containing admixed tar was collected on the filter. This residue was dried and worked up in ether — which did not completely dissolve the residue. The undissolved portion was removed by filtration — it appeared to be an inorganic residue. The ether solution after evaporation of the ether yielded a yellow resinous substance (total weight 0.48 g), in which a small amount of crystalline material was found. The resinous material was dissolved in a small quantity of alcohol with warming; the solution obtained had a yellow color. A white crystalline material separated from the alcohol solution on cooling and scratching with a glass rod; the dried product weighed 0.04 g (1%). Recrystallization from alcohol or ligroin gave a crystalline product with an m.p. of 187°.

2.821 mg substance: 8.542 mg CO_2; 1.950 mg H_2O. 2.806 mg substance: 8.491 mg CO_2; 1.923 mg H_2O. 3.147 mg substance: 0.265 ml N_2 (18.5°, 745 mm). 3.198 mg substance: 0.271 ml N_2 (18.5° 748 mm). 0.0052 g substance; 0.0696 g camphor: Δt 10.5°. 0.0047 g substance; 0.0819 g camphor: Δt 8.25°. 0.0414 g substance: 4.08 g benzene: Δt 0.17°. 0.0704 g substance; 4.08 g benzene: Δt 0.29°. Found %: C 82.65, 82.60; H 7.67, 7.73; N 9.66, 9.77; M 284.6, 278.3, 304.4, 303.5. $(C_{10}H_{11}N)_2$. Calculated %: C 82.71; H 7.64; N 9.65; M 290.4.

From the above given data it follows that the product prepared was a dimer of dihydrolepidine $(C_{10}H_{11}N)_2$.

SUMMARY

1. Performance of the study showed that lepidine, on chemical reduction in acid medium, yields in addition to tetrahydrolepidine a new crystalline product which is not obtained by reduction of lepidine via other methods.

2. It was shown that this product was a heretofore unprepared isomer of dihydrolepidine dimer, which differed from the dimer of dihydrolepidine obtained on electrolytic reduction of lepidine in acid and alkaline media.

3. It has been shown that there is no difference in principle between chemical reduction of lepidine using potassium or sodium amalgam and the electrolytic reduction of lepidine in alkaline medium on a mercury cathode.

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** See Consultants Bureau English Translation, p. 1301.

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REDUCTION OF THE ALKALI METAL NORMAL SULFATES BY HYDROGEN AND AMMONIA

Viktor I. Spitsyn and M. A. Meerov

The literature data concerning the behavior of alkali metal sulfates, upon calcination in a current of hydrogen, do not appear to be completely exhaustive, and in certain cases contradict themselves,

Cobb [1] demonstrated that dry hydrogen begins to react with sodium sulfate at 530-540°, with the evolution of hydrogen sulfide. The reduction proceeds more rapidly at 900°. Tiede and Reinicke [2] determined a temperature of 700-750° for this reaction, and they noticed that in addition to sulfide, a quantity of polysulfide was also formed; Lewis, Randall and Bychowsky [3] observed the formation of noticeable quantities of hydrogen sulfide and the sublimation of free sulfur when hydrogen was reacted with sodium sulfate in the temperature range of 220-250°. The residue gave an alkaline reaction and did not contain sulfide as a constituent. According to the data of Berzelius [4] and Regnault [5], potassium sulfate is reduced to the sulfide by hydrogen at red heat. Berthelot [6] records secondary reactions: due to interaction of the formed water, caustic alkali is formed; moreover, the residue contains potassium polysulfide as a constituent. In the escaping gaseous products are present hydrogen sulfide, water and free sulfur vapors.

Tiede and Reinicke [2], in a work devoted to the derivation and properties of the phosphorescent sodium and rubidium sulfides, studied the conditions for conversion of rubidium sulfate into sulfide by a current of hydrogen. The authors indicated that Rb_2SO_4 is partially reduced by hydrogen at a temperature of 500°. At the same time noticeable hydrogen sulfide evolution was observed. At 700°, the resulting sulfide vaporized rapidly. In order not to lose large quantities of the sulfide because of its volatility, Tiede and Reinicke heated rubidium sulfate in the hydrogen current for only a short time (about 5 minutes), at a temperature of 650°.

The authors (present article) did not find literature data on the behavior of the normal sulfates of the alkaline elements when calcined in a current of ammonia.

In the present work the behavior of the normal alkali metal sulfates upon heating with hydrogen and with ammonia currents was studied, and their temperature condition for reduction, was determined.

TABLE 1

Analysis of the Alkali Metal Sulfates

Compound	Content SO_3 (%)	
	Found	Calculated
Li_2SO_4	72.81	72.77
Na_2SO_4	56.31	56.34
K_2SO_4	45.89	45.95
Rb_2SO_4	31.04	29.98
Cs_2SO_4	22.22	22.14

Earlier, one of us [7] described the preparation of the necessary alkali metal sulfate samples. Analysis for SO_3 content of the samples used was conducted by the usual method. Results are quoted in Table 1.

A weighed portion of the sample, in a porcelain boat, was placed into a second protective boat and was introduced, at room temperature, into the working tube of an electric oven. The air was then removed from the apparatus by a current of the gas in question. The oven temperature was gradually raised, and the rate at which the gas passed through was determined to be approximately equal to 6 liters per hour. After termination of the experiment, the product was also cooled in a current of the same gas applied.

The hydrogen required for the experiments was obtained by the usual procedure from a Kipp apparatus, and was dried, before entering into the working tube of the oven, by passing through Tishchenko flasks containing concentrated sulfuric acid. Gaseous ammonia was produced by heating commercial aqueous solution, and was passed through drying columns containing lumps of sodium hydroxide and calcium oxide.

Calcination of the normal sulfates of the alkali metals in a current of hydrogen has shown that all of them, including lithium and cesium sulfates, can be transformed into the sulfides at the appropriate temperatures, concerning which reduction there are no data in the literature. Thus, for example, a weighed portion of cesium sulfate was heated in a stream of hydrogen for 1 hour at 600-620°. The product was obtained as a slightly-caked mass, with faint hydrogen sulfide odor. After removal from the tube, the sample had a yellowish color, changing rapidly in the dessicator to a greenish color, with a narrow black border around the edges of the boat. The product was analyzed. On one weighed portion, sulfate-sulfur was determined, on the second, total sulfur, according to Tredvel [8]. The sulfide-sulfur content was calculated by difference. Analysis showed that the product contained 99.15% Cs_2S and 0.85% Cs_2SO_4. The reduction process evidently took place according to the following equation: $Cs_2SO_4 + 4H_2 = Cs_2S + 4H_2O$. Calcination of the other normal sulfates of the alkali metals in a current of hydrogen yielded analogous results. The product remaining in the boat after calcination of lithium sulfate was light-yellow in color, of the sodium sulfate — yellow-pink, and of the potassium and rubidium — brick-red, the cesium sulfate, as indicated above, — yellow-green.

Judging from the color of the described products, the reduction process for the alkali metal sulfates, using hydrogen, is actually quite complicated. Thus, in the case of the potassium and rubidium sulfates, and partially with sodium, there are undoubtedly formed the polysulfides which are red in color. The mechanism of reaction was investigated further. For the present work it was of interest only to determine reaction temperatures for the sulfates with hydrogen, in order to compare their stability under other conditions.

TABLE 2

Calcination of the Normal Sulfates of the Alkali Metals in the Hydrogen Current. Duration of each experiment 1 hour

Temperature (°C)	Weighed portion of sample				
	Li_2SO_4 0.0784 g	Na_2SO_4 0.2025 g	K_2SO_4 0.2069 g	Rb_2SO_4	Cs_2SO_4 0.0396 g
570	—	—	—	—	0.0396
600	—	—	—	—	0.0396
620	0.0784	—	0.2069	0.1386	0.0260
650	0.0784	—	0.2069	0.1386	—
670	0.0456	0.2025	0.1565	0.1218	—
700	—	0.2025	—	—	—
720	—	0.0978	—	—	—

The experimental results for the control series of experiments are quoted in table 2.

The calcination of the alkali-metal normal sulfates in a current of ammonia has indicated that here, too, the conversion into sulfides occurs at defined temperatures. Thus, as an illustration, the normal sulfate of cesium reduces to sulfide in the temperature range 740-770°. The rate of reaction increases sharply with increase in temperature. After calcination for 1 hour at 820°, the reduction product possessed a strong hydrogen sulfide odor and changed color rapidly in the air and in a dessicator. Upon withdrawal from the oven as brick-red, it changed in color to rose-yellow, yellow-gray, and finally into yellow-green with a black rim around the edges of the boat. Analysis showed that the final product contained 61.35% of the sulfide. The reduction of sulfates to sulfides by gaseous ammonia occurs at the expense of the hydrogen which results when the ammonia breaks down under the conditions of high temperature applied.

The calcination experimental results for the normal alkali metal sulfates are quoted in Table 3.

TABLE 3

Calcination of the Alkali Metal Normal Sulfates in a Current of Ammonia. Duration of each experiment 1 hour.

Temperature (°C)	Weighed portion of samples				
	Li_2SO_4 0.1346 g	Na_2SO_4 0.1548 g	K_2SO_4 0.1990 g	Rb_2SO_4 0.1822 g	Cs_2SO_4 0.0302 g
670	0.1346	—	—	—	—
700	0.1346	—	—	—	—
720	0.1205	0.1548	0.1990	0.1822	0.0302
740	—	—	—	—	0.0302
750	—	0.1548	0.1990	0.1822	—
770	—	0.1214	0.1990	0.1822	0.0108
790	—	—	—	0.0758	—
800	—	—	0.1778	—	—

All products remaining in the boats, after the indicated experiments, gave off a hydrogen sulfide odor in the air. Their coloration was analogous to that of the products derived from calcination in a hydrogen current. In the case of cesium sulfate, only, the reduction product, as has already been indicated, was not a light yellow-green, but brick-red color, at the expense of the polysulfide present in considerable amount. Evidently this was related to the higher temperature for the reduction period of cesium sulfate in ammonia current, as compared with the hydrogen action.

The abrupt temperature point at which reaction of the alkali sulfate with hydrogen beings should be noted. For example, a one-hour calcination of sodium sulfate in a hydrogen current, at a temperature of 700°, did not show any change in the weighed portion, whereas, a temperature increase to 720° led to a weight loss of more than 50% (Table 2). A weighed portion of cesium sulfate (of the 0.1 g series) showed a weight loss of 4.8% after 1 hour calcination in a current of ammonia at 770° and at 820° – 17.2%. A comparison is given in Table 4 for the temperatures at which reaction starts between the alkali metal normal sulfates and hydrogen and ammonia.

The sulfates investigated generally reduce within closely-defined temperature conditions: 620-720° with hydrogen action, 720-800° – in the case of ammonia use. The higher temperature required for reduction by ammonia (more accurately by its decomposition products) evidently is due to the smaller concentration of hydrogen in this case.

The reduction period temperature of the alkali sulfates by hydrogen is approximately 300° lower than the temperature for noticeable thermal dissociation of the lithium and sodium sulfates, and the volatilization of the potassium, rubidium, and cesium sulfates in the air, as determined by Spitsin and Shostak [7]. In the case of ammonia, this difference is 200-230°.

Relatively speaking, sodium sulfate seems to be the most stable in the hydrogen current (beginning reaction period temperature 720°). The highest reduction temperature period for ammonia action corresponds to potassium sulfate (800°), although in this sense sodium and rubidium sulfates approach the former (Table 4).

Thus, the least active, with regard to reducing agent action, appears to be the sulfate of that alkali element which stands close to the center of the group in the periodic system.

Fialkov and Shargorodsky [9] have also observed a similar change in chemical activity upon calcination of alkali sulfate mixtures with silica: potassium sulfate proved to be the most stable compound. As Spitsin and Shostak have demonstrated [7], the thermal instability is manifested only by lithium and (to a lesser extent) by sodium, at 1200°. Apparently the effect of chemical reagents (hydrogen, ammonia, silica) proves to be a more discriminating medium for experimental determination of differences in stability of the alkali metal sulfates than simple calcination.

TABLE 4

Temperature Comparison for the Reduction Periods of the Normal Alkali Metal Sulfates by Hydrogen and Ammonia

Compound	Temperature for the Transition Period into Sulfide (° C)	
	In the hydrogen current	In the ammonia current
Li_2SO_4	670	720
Na_2SO_4	720	770
K_2SO_4	670	800
Rb_2SO_4	670	790
Cs_2SO_4	620	770

The increase in stability of the normal sulfates upon passing from lithium to sodium or to potassium, is evidently connected with the weakening of "counterpolarization" in the compounds, due to an increase in the ionic radius of the cation. The subsequent decrease in stability, on passing to the sulfates of rubidium and cesium, may be explained by the increase in self-polarization of the ions of the alkali elements as the result of a considerable increase in their radii.

SUMMARY

1. The reduction period temperatures of the normal alkali metal sulfates, for conversion to the sulfides, by the action of hydrogen and of ammonia, were studied.

2. It was determined that lithium, sodium, potassium, rubidium and cesium sulfates enter into the indicated reactions at close temperature conditions: 620-720° in the case of hydrogen, and 720-800° in the case of ammonia (with the respective products of decomposition).

3. As regards hydrogen, the most stable proves to be sodium sulfate, and as regards ammonia – potassium sulfate.

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THE EXTRACTION OF PENTAVALENT VANADIUM FROM HYDROCHLORIDE SOLUTIONS USING ORGANIC SOLVENTS

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Extraction methods for the recovery and separation of elements are, without doubt, of analytical interest, due to the rapidity and convenience of execution.

The earlier discussed [4] example of trivalent iron, where the relation between the extracting power and the structure of organic solvents was shown, indicates that there are still many uninvestigated and unutilized possibilities in this field.

In the present article, the extraction of pentavalent vanadium from hydrochloride solutions is considered, the presence of which causes complications in many analytical investigations; for this reason, the removal of vanadium from solution, or even the major portion of it, is frequently quite desirable.

Extraction recoveries of various vanadium compounds, used chiefly for qualitative reactions, are described in the literature. The compound formed from vanadium plus 8-hydroxyquinoline is extracted with chloroform [11, 13, 14], or by isoamyl alcohol. In the presence of rhodanides, vanadium is extracted by ethyl acetate [9]. The same solvent extracts vanadium diethyldithiocarbamate very fully [7].

Pentavalent vanadium is slightly extracted by diethyl ether [1] from hydrochloric acid solution, considerably extracted by amyl acetate [15], and by diisopropyl ether, with a distribution coefficient of about 0.3 [10]. The recoverability of pentavalent vanadium from hydrochloride solutions, when using diisopropyl ether, interferes with the separation of iron from vanadium, when the latter solvent is used to extract iron. Lingane and Meites [12], in this connection, have studied in detail the extraction of vanadium by diisopropyl ether, for the express purpose of determining the conditions under which vanadium does not extract. According to their data, conversion of vanadium to the tetravalent state is essential.

We considered it possible to regard the process of extraction of elements by oxygen-containing organic solvents from acid solutions as being due to oxonium-compound formation. From such a viewpoint, the varied behavior of the different classes of oxygen-containing organic compounds was to be expected.

V. V. Chelintsev [6], who studied the interaction of oxygen-containing organic subtances with C_2H_5OMgI, also considered this interaction to be due to the formation of oxonium compounds, and upon the heat of reaction effect, arranged the oxygen-containing organic compounds in the following order, according to their tendency to form oxonium compounds:

$$\begin{array}{ccccccccccc} \mathrm{R\cdot O\cdot R} & < & \mathrm{R\cdot OH} & < & \mathrm{R\cdot CO\cdot OH} & < & \mathrm{R\cdot CO\cdot OR} & < & \mathrm{R\cdot CO\cdot R} & < & \mathrm{R\cdot CO\cdot H} \\ \text{Ethers} & & \text{Alcohols} & & \text{Acids} & & \text{Esters} & & \text{Ketones} & & \text{Aldehydes} \end{array}$$

In consequence, according to V. V. Chelintsev, ethers are least inclined to form oxonium compounds, while aldehydes are the most prone.

Beside the tendency of oxygen to complex formation, the ease of oxonium compound formation undoubtedly depends also upon the individual characteristics of the organic compound, upon the nature of the acid radical, and upon many other factors. However, in the case of iron extraction from hydrochloride solution, the V.V. Chelintsev order is approximately maintained, as was earlier indicated [4], although V. V. Chelintsev determined this order from the investigation of oxonium complexes of an entirely different nature. Ethers extract iron to a lesser degree than do aldehydes or ketones.

With pentavalent vanadium, conformities to established rule proved to be more complex, but in such case the combinations with carbonyl oxygen no doubt extract vanadium more completely than do the ethers.

We have determined the distribution of vanadium between hydrochloric acid and organic solvents, in order to evaluate the ability of solvents to extract pentavalent vanadium from hydrochloric acid solutions.

3.00 ml of pentavalent vanadium solution in hydrochloric acid ($NaVO_3$ + HCl), with a content of 3.00

mg/ml V, was shaken with 1.0 ml of organic solvent in a small separatory funnel, of 10 ml capacity, made from a cut-off buret, equipped with ground glass stopper. The final ratio of volume between organic solvent and hydrochloric acid was always 1:3. In some experiments, specific samples were selected in such initial ratio of volumes, that after shaking, followed by separation into layers, it would be equal to 1:3.

The mixture was shaken vigorously for about 100 times for a period of approximately one minute. Longer shaking was not carried out in order to avoid any considerable reduction of V^V to V^{IV}. Even so, some solvents reduced to V^V to V^{IV} so rapidly that their investigation proved impossible.

After separation of the layers, the V^V content in the hydrochloride layer was determined — by titration with Mohr's salt and phenylanthranilic acid — and V^{IV} colorimetrically by the color reaction of VO_3^-, described elsewhere by the author, which permits determinations of V^{IV} in the presence of VO_3^- and readily-oxidizable organic substances [3].

The recovery of V^V from hydrochloric acid was studied at concentrations of 3-, 4-, 5-, 6-, 7-, 8- and 9-normal.

The results obtained are indicated in Table 1 and Figure 1.

TABLE 1

Vanadium (V^V) Distribution Coefficients

$(K = \dfrac{\text{conc. } V^V \text{ in organic solvents}}{\text{conc. } V^V \text{ in hydrochloric acid}})$

Between Organic Solvents and Hydrochloric Acid for a Volume Ratio of 1:3 for the Layers. Initial concentration of $V^V = 3$ mg/ml; t = 18°

Order No.	Organic solvent	Normality of hydrochloric acid							Note
		3	4	5	6	7	8	9	
	Ethers								
1	Diethyl ether	–	–	Traces		–	–	–	According to the lit. data [1]
2	Diisopropyl ether	–	–	–	–	–	0.28	–	According to the lit. data [10]
	Alcohols								
3	Isoamyl alcohol	–	–	–	1.8	4.5	9.0	–	
	Acids								
4	Caprylic	–	–	–	–	0.18	0.45	–	
	Esters								
5	Ethyl acetate	–	–	–	–	1.7	–	–	
6	Ethyloxalate	–	–	0.03	–	0.9	1.2	–	
7	Amylformate	–	–	–	3.3	14	28	–	
8	Amylacetate	0.06	0.24	0.7	2.0	11	32	72	
8a	Amylacetate	0.09	0.15	0.27	1.8	8.4	31	–	• In the presence of Fe^{III}, $V^V : Fe^{III} = 1–2$.
9	Methylbenzoate	–	–	–	–	0.15	0.6	–	
	Ketones								
10	Methylbutylketone	<0.03	~0.6	~2.4	~4.8	~20	?	–	In 8N HCl, rapid reduction to V^{IV}
11	Cyclohexanone	–	–	–	–	?	–	–	Reduction to V^{IV} too rapid. Reading impossible.
12	Methylbenzylketone	–	–	–	–	?	?	–	Complete reduction to V^{IV} in 7 and 8N HCl within a few seconds.
13	Acetophenone	–	–	0.6	2.4	9.0	51	–	

* According to the experiments of Wellsand Hunter, carried out under different conditions, pentavalent vanadium is recovered by amyl acetate in 14.3 % yield from solution in concentrated hydrochloric acid, containing 4% sulfuric acid [15].

The data of Table 1 indicate that recovery of pentavalent vanadium from hydrochloric acid solutions depends greatly upon the HCl concentration.

The considerable deviation in 8N-HCl for the ethyl oxalate is explained by the considerable increase in its solubility at the increased hydrochloric acid concentration which decreases the value of the distribution coefficient, as has been indicated elsewhere [10].

As with trivalent iron, ketones gave the best recovery, but their rapid reduction of V^V to V^{IV} made it difficult to use ketones.

Acetophenone $CH_3 \cdot CO \cdot C_6H_5$ extracts vanadium much poorer than methylbutylketone $CH_3 \cdot CO \cdot CH_2 \cdot CH_2 \cdot CH_2 \cdot CH_3$. But acetophenone has the advantage of great resistance to oxidation. The ease with which highly purified acetophenone solidifies upon decrease of temperature (m.p. 20°) causes no difficulty, since it is always possible to add enough constituent to the acetophenone.

The good recovery of vanadium was probably to be expected upon use of methylbenzylketone $CH_3 \cdot CO \cdot CH_2 \cdot C_6H_5$. However, due to the unusually-rapid reduction of V^V to V^{IV}, it was not possible to investigate, at room temperature, the extracting action of methylbenzylketone.

Esters, including formates, also extract well, pentavalent vanadium, and reduce it rather poorly.

The more complete recovery in the case of amyl acetate, as compared with ethyl acetate and ethyloxalate, can be explained by less solubility in hydrochloric acid of the amyl acetate, due to its large molecular weight.

The poor action of methylbenzoate appears to be the consequence of the presence of the benzene ring, combined with the CO group. R. Dodson, G. Forney and E. Swift indicate that recovery of V^V increases in the presence of large amounts of Fe^{III}. In the presence of small (only double) amounts of Fe^{III}, the author did not observe any substantial influence of Fe^{III} upon V^V recovery. The results obtained (Table 1, 8a) differ in value from the behavior of V^V (Table 1, 8) not greater than experimental error.

The reduction of pentavalent vanadium to the poorly-extractable tetravalent, under the influence of the organic solvent added, interferes more seriously with the extraction of vanadium. A certain quantity of vanadium always has time to reduce to the tetravalent state, and this quantity remains unrecovered.

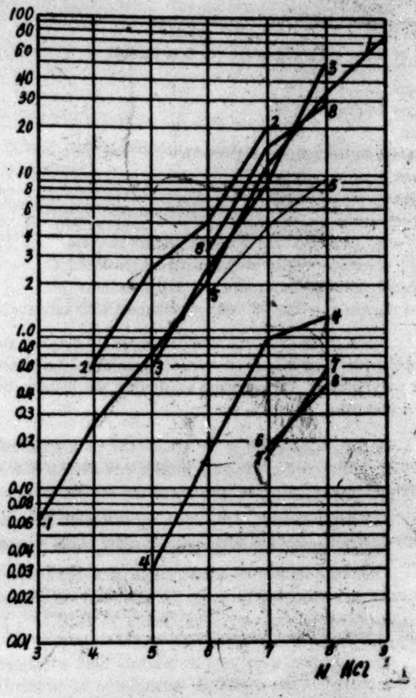

Fig. 1. Vanadium (V^V) distribution coefficients between hydrochloric acid and organic solvent at volume ratio of acid: solvent = 3:1 at 18°. 1 - amylacetate; 2-methylbutylketone; 3-acetophenone; 4-ethyloxalate; 5-amyl alcohol; 6-caprylic acid; 7-methylbenzoate; 8-amylformate. On the ordinate axis, logarithmic scale.

For these reasons, one must consider that the aliphatic ketones, which extract very well, but at the same time reduce easily the pentavalent vanadium, are of little use, and therefore, to be recommended instead are acetophenone and the ester, which, though less efficient, are more resistant to oxidation.

The oxidation potential of V^V, as is known [5], increases with increase in acidity. Since the efficiency of V^V recovery also increases with increase in acidity, this property is found to be of little value for the purpose of vanadium extraction. The reduction rate of V^V to V^{IV} decreases with decrease in temperature. This circumstance, on the other hand, is found to be favorable, since the stability of oxonium complexes increases with decrease in temperature.

Table 2 and Fig. 1 will give some idea of the practical reduction rate of V^V under the influence of amyl acetate, for given extraction conditions.

TABLE 2
Rate of Reduction of V^V to V^{IV} in Stirred Mixtures: V^V (3 mg/ml), 8N HCl + amyl acetate; t = 20°.

Time from start of test	V^{IV} formed (in mg/ml)	(in % of initial)
0 hours	–	0.0
0 hours 30 min	0.06	2.0
1 hour	0.075	2.5
2 hours	0.15	5
4 hours	0.22	7.3
6 hours	0.36	12

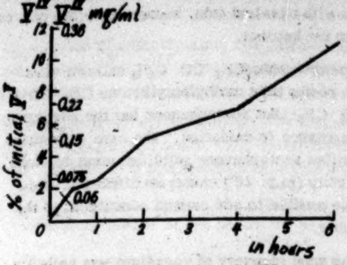

Fig. 2. Concentration increase of V^{IV} in the system: 3 volumes of 8N HCl with 3 mg/ml of V^V + 1 volume of amylacetate (with stirring); t = 20°.

In these, the rate of concentration increase of V^{IV} is represented for a vigorously-stirred mixture of pentavalent vanadium solution, at a concentration of 3.0 mg/ml of V^V in 8N HCl (3 volumes) with amylacetate (1 volume at 20°).

Since the distribution equilibrium of V^V between the acid layer and the solvent layer is reached rapidly, it is desirable to carry out the extraction quickly. For example, upon recovery of V^V from its solution in 8N–HCl, using amylformate, the partition coefficient was found to be equal to 9.3 with 100 shakings, and equal to 7.5 with only 5 shakings.

As can be seen, the reduction rate of V^V is usually not so great. This situation permits consideration of recovery, from hydrochloric acid solutions, of pentavalent vanadium by the extraction method, to be a real possibility.

The completeness of V^V recovery should not give cause for reservation, since the recovery coefficient of V^V from 9N–HCl, using amylacetate, is close to the recovery coefficient of iron, using diethyl ether.

The latter method is considered to be acceptable in analysis, and so, from the viewpoint of incomplete iron extraction, there are no particular grievances to present.*

Analytical Potentialities

The optimum conditions for possibly more complete extraction of vanadium can be formulated in the following manner. The vanadium should be in the pentavalent state. It is essential to extract from hydrochloric acid which is not less than 8N. In order not to lower the hydrochloric acid concentration, particularly during the course of multiple extractions, it is useful to saturate the solvent beforehand with hydrogen chloride, by stirring with fuming hydrochloric acid.

Amylacetate, amylformate, or their mixture with acetophenone, can be used for drastic recovery of pentavalent vanadium. The work should be carried out as rapidly and at as low temperature as is possible, carrying out repeated extractions if necessary.

For recovery of vanadium from small volumes, the work can be done in an ordinary test tube, using a capillary with a rubber (pear-shaped) syringe for removal of the organic solvent layer. Complete extraction can be carried out within a few minutes.

If recovery is carried out with small portions of solvent, then practically complete vanadium recovery can be attained with a loss of about one and one-half times the volume of solvent per volume of solution extracted (Table 3).

For evaluation of the potentialities for application of the described extraction methods for the separation of elements, there should be taken into account the general rule of element extraction by oxygen-containing organic solvents.

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* It should be noted that in the case of iron, the incompleteness of iron recovery is also conditioned by the reduction of extractable Fe^{III} to non-extractable Fe^{II}. In this connection, a search was carried out for a solvent more resistant to oxidation than ordinary diethyl ether, and as a result, substitution of the less easily oxidized diisopropyl ether for diethyl ether has been recommended [8, 10].

If it is considered that transferral of elements from the hydrochloric acid layer to the organic solvent layer is related to the formation of compounds of the oxonium salt type, it is reasonable to assume that only anions, and not cations, can be extracted.

But apparently among anions, too, all are not extracted to the same degree. Metal complex ions, of the type $MeHal_n^{m-}$ containing halogens, and their analog rhodanide extract well. The rhodanide metal complex anions extract particularly well.

TABLE 3

The comparative extraction of pentavalent vanadium from pure solutions of $NaVO_3 + HCl$; $t = 20°$.

The original solution contained 18 mg of V^V in 6 ml of 8 N HCl. Seven consecutive extractions, 1.5 ml of solvent for each were carried out. The solvent was removed with a capillary

Recovery results	Solvent	
	amylacetate	amylformate
Vanadium (V^V) remaining in total volume	0.02 mg	Not found (i.e. < 0.003 mg)
V^{IV} remaining in total volume	0.09 mg	0.06 mg
Percentage vanadium recovery with regard to initial quantity	0.45%	0.3%
Percentage vanadium recovery	99.45%	99.7%

The extractability of one or another element is determined mainly by its ability to form only slightly dissociated complex anions, under the conditions of extraction. Because the iodides, or rhodanides, have greater capacity for complex anion formation than do chlorides, a greater number of elements are extracted in the presence of iodides or rhodanides than in the presence of chlorides alone.

It can be assumed that the very fact that an element can be recovered from hydrochloric acid solution which does not contain other reagents is an indication that the element may exist in the form of a complex anion, under the conditions of extraction. Thus the ability of elements to be extracted is characteristic for the elements which give the reactions, and requires the presence of the elements in anionic form. For example, as studied elsewhere [2], the ability of a series of elements to give color reactions with colored organic cations is based upon the formation of complex ions by the elements. Color reactions of this type also give a greater amount of elements in the presence of iodides or rhodanides, than in the presence of chlorides alone.

The ability of some elements to precipitate in the form of complex anions by the action of organic bases, of which these color reactions are found to be particular cases, is directly related to the degree of extractability of the elements by oxygen-containing organic solvents. For example, the readily-precipitating anions of BiI_4^-, $CdI_4^{=}$ have the capacity for being extracted.

This relation is favorable in practice, since the presence of reactions of one kind permits the assumption of the possibility for the existence of a reaction of another type, also. From the ability to precipitate and to give color reactions with colored organic cations the extractability tendency can be judged, and vice versa. The only prerequisite is the consideration of different conditions for completion of reaction; the color reaction, and precipitation, are usually completed at relatively low acidity, and during extraction the acidity is very high. Under such differing conditions, one and the same element may form ions of different composition and character.

SUMMARY

1. It is possible to effect practically complete recovery of pentavalent vanadium from hydrochloric acid solutions by extracting vigorously with oxygen-containing organic solvents, for example the esters (amylacetate, amylformate), or acetophenone.

2. Aliphatic ketones extract V^V better, but reduce V^V to V^{IV} too rapidly. The completeness of extraction is limited by the partial reduction of pentavalent vanadium into the non-extractable tetravalent state.

3. The extraction of elements by oxygen-containing organic solvents is considered to be the result of compound formation of the oxonium salt type. The ability of elements to form complex anions determines both the possibility for extraction of these elements, and their ability to be precipitated by organic bases, as well as their ability to give color reactions with colored organic cations.

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A PHYSICO-CHEMICAL ANALYSIS OF PYRIDINE-NITROPHENOL INTERACTION

D. E. Dionisyev and A. D. Kirillova

Pyridine is found to be a good complexing agent, due to the presence of a tertiary nitrogen atom, which is an electron donor. The interaction of pyridine and phenol has been investigated by a number of authors [1,2,3], who determined that pyridine forms complexes with phenol of the composition $C_5H_5N \cdot C_6H_5OH$ and $C_5H_5N \cdot 2C_6H_5OH$. It was of interest to clarify the extent to which introduction of nitrogroups into the phenol molecule effects the nature of its reaction with pyridine. With this purpose in mind, the authors have investigated the systems of pyridine with o- and p-nitrophenols and with 2,4-dinitrophenol by the methods of fusibility, viscosity, density and electroconductivity.

Fusibility investigation was carried out by the visual-polythermal method. For density determination, a viscometer of the covered type was used. Density was determined with narrow-necked pycnometers of 4-5 ml. volume. Electroconductivity measurement was carried out by the Kolrausch method and light generator and indicating light, instead of by telephone. The investigation was carried out in a hermetically-sealed vessel with smooth platinum electrodes. Temperature of the thermostat was maintained with an accuracy of ±0.1°.

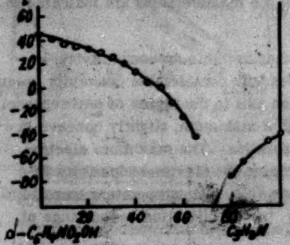

Fig. 1.

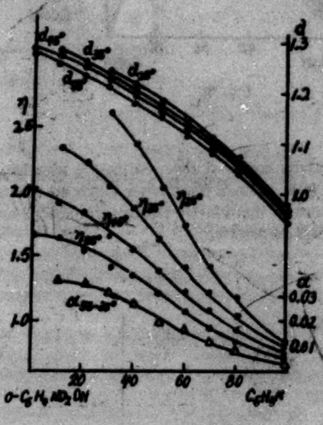

Fig. 2.

Pyridine was dried over caustic potash and fractionally distilled. The fraction with b.p. 115.5° at 760 mm pressure and d_4^{25} 0.977 was distilled into ampoules and sealed. o-nitrophenol was recrystallized three times from alcohol. Melting point of the purified sample was 44.5°, d_4^{45} 1.286. p-Nitrophenol, recrystallized repeatedly from water, possessed a m.p. of 113°, d_4^{113} 1.286. Dinitrophenol, purified by double recrystallization from alcohol, melted at 111.3°, d_4^{115} 1.44. All mixtures were calculated in mole percentages.

o-Nitrophenol-Pyridine System. This system was investigated by Ampola and Rimatori, by fusibility, but the authors did not arrive at any conclusions concerning interaction of the components, since they investigated only 7 mixtures in all. The present authors investigated the given system in more detail by the fusibility method. Results of the investigation are represented in Fig. 1. The mixtures in the composition range from 65 to 80 mole % of pyridine became very viscous upon cooling, but did not crystallize. All attempts to induce crystallization by the addition of seeding substances, both mixtures of similar composition, and other compounds, were unsuccessful. The mixtures solidified into transparent glassy masses at temperatures below −90°.

By viscosity Bramley [1] investigated the given system at temperatures of 30, 40, 60 and 80°. The curves obtained by him are found to be slightly convex toward the composition axis, with no outstanding points. Therefore, Bramley concluded that there is no chemical interaction between pyridine and o-nitrophenol. We have repeated investigations of the viscosity and the density of the given system at temperatures of 25, 35, 45 and 55°.

Results of the measurements are represented in Fig.2.

As can be seen from Fig. 2., the density isotherms, d, represent curves with concavity toward the composition axis, which expresses the occurrence of a certain amount of contraction in the system.

The viscosity isotherms, η, at all temperatures, are represented as S-like curves with a point of inflection at about 50% pyridine. The curve for the absolute temperature coefficient of viscosity, α, for the temperatures range 55-35°, also represents an S-shaped curve with inflection point at about 50% pyridine. All of this permits the deduction that a compound is formed in the system, of the composition $C_5H_5N \cdot o\text{-}C_6H_4NO_2OH$. The same S-shaped viscosity isotherms were obtained by A. D. Vinogradova, A. M. Tikhomirova and N. N. Efremov for the pyridine-phenol system [3]. In that work the authors make the assumption that in the case of the nitrophenols there might be expected curves of the same type. Our investigations have confirmed the above-indicated situation. The electroconductivity of the system was studied at temperatures of 24, 45 and 55°. Results of the measurements are indicated in Fig. 3.

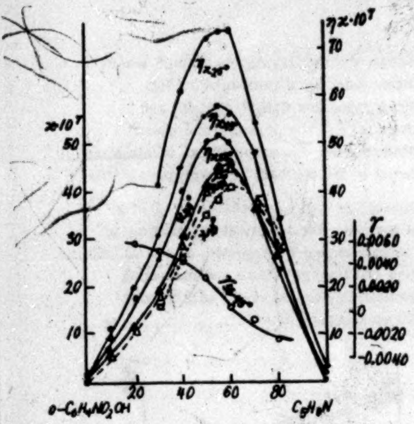

Fig. 3.

The isotherms of electroconductivity, κ, represent curves with considerable convexity toward the composition axis in the region of o-nitrophenol, passing through a maximum, slightly concave in the region of pyridine. The maximum electroconductivity comes at about 60 mole % pyridine. At about 70 mole % of pyridine the electroconductivity isotherms intersect at a point, after which the electroconductivity of the mixture falls with temperature increase. The curve for the relative temperature coefficient of electroconductivity, γ, has an inflection in the range of 50 mole % of pyridine.

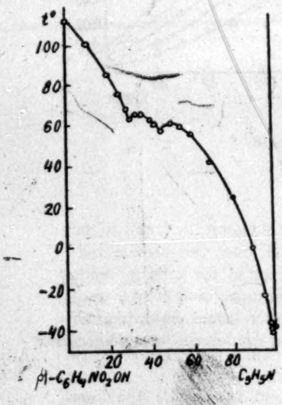

Fig. 4.

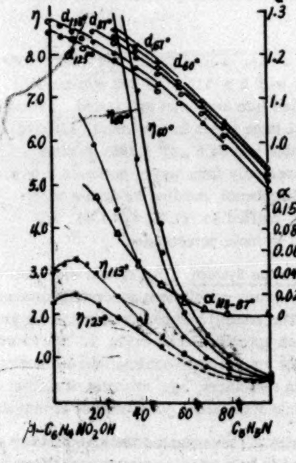

Fig. 5.

The existence of positive and negative electroconductivity coefficients for one and the same system was observed by M. I. Usanovich upon examination of the system $H_2SO_4-(C_2H_5)_2O$ [5] and F. I. Terpugov upon examination of the system $AsCl_3-(C_2H_5)_2O$ [6] and others. M. I. Usanovich [7,8] theoretically substantiated the reasons for the appearance of a negative electroconductivity temperature coefficient.

Correction of electroconductivity for viscosity, $\eta\kappa$, did not change the course of the curves, but somehow shifted the maximum closer to 50% pyridine. Electroconductivity investigation has confirmed the presence of a compound in the liquid phase of composition $C_5H_5N \cdot \underline{o}\text{-}C_6H_4NO_2OH$.

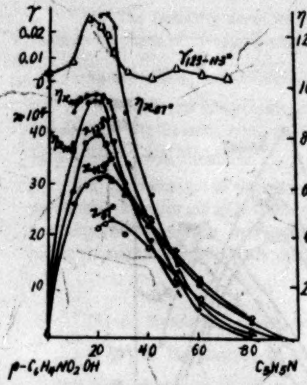

Fig. 6.

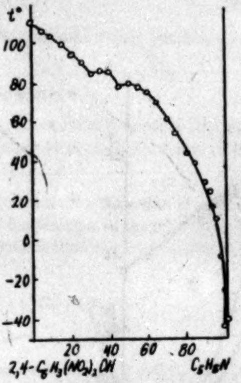

Fig. 7.

p-Nitrophenol-Pyridine System, up to the present time, has not been investigated. The results of our fusibility investigation are represented in Fig. 4.

The melting curve has two maxima, corresponding to 33.3 and to 50 mole % of pyridine, with melting points of 66 and 61.5°. This points to the formation of two compounds in the solid phase of the composition $C_5H_5N \cdot \underline{p}\text{-}C_6H_4NO_2OH$ and $C_5H_5N \cdot 2\underline{p}\text{-}C_6H_4NO_2OH$. The viscosity and the density of the system were determined at temperatures of 60, 67, 87, 113, 123°. Investigation results are presented in Fig. 5.

Isotherms, η, isotherms, at temperatures of 87, 113 and 123°, are represented as S-shaped curves with an inflection point of about 33.5 mole% of pyridine. It was possible only to take the 60, 67° isotherms up to 30 mole % of pyridine, but from their appearance it may be assumed that they too take the shape of S-curves.

The absolute temperature-density coefficient, a, curve for the temperature range 113-87° also takes an S-form with an inflection point at about 34 mole% of pyridine.

By the viscosity method the presence in the liquid phase of a combination between pyridine and $\underline{p}$-nitrophenol of the composition $C_5H_5N \cdot 2\underline{p}\text{-}C_6H_4NO_2OH$ was confirmed. The electroconductivity for the system was measured at three temperatures, 87, 113 and 123°. The measurement results are presented in Fig. 6.

The isotherms for electroconductivity, κ, at all temperatures are represented by curves which are concave to the composition axis in the $\underline{p}$-nitrophenol range, passing through a maximum, and vice versa, convex to the composition axis in the pyridine range. The electroconductivity curve form is analogous to that of the pyridine-iodine chloride system investigated by Ya. A. Fialkov and I. D. Muzyka [9]. The electroconductivity maximum at 87° comes at about 25 mole % of pyridine. With a temperature increase, the maximum is shifted toward $\underline{p}$-nitrophenol. The curve for the relative temperature coefficient of electroconductivity has two maxima in the temperature range 123-113°, and 213-87°. Correction of electroconductivity for viscosity, $\eta\kappa$, did not change the course of the curves, and the maxima remained almost unchanged for the same compositions. The investigation of viscosity and of electroconductivity confirms the presence of one of the compounds of the composition $C_5H_5N \cdot 2\underline{p}\text{-}C_6H_4NO_2OH$, which was determined by the fusibility method.

2,4-Dinitrophenol-Pyridine System was investigated by the authors for the first time. The results of fusibility investigation are presented in Fig. 7.

As with p-nitrophenol, the fusibility curve has two maxima, corresponding to the compositions 33.5 and 50 mole % of pyridine, with melting points of 86.5 and 80°. It follows that in the solid phase there are to be found two combinations of pyridine and 2,4-dinitrophenol, of the composition $C_5H_5N \cdot 2,4\text{-}C_6H_3(NO_2)_2OH$ and $C_5H_5N \cdot 2[2,4\text{-}C_6H_3(NO_2)_2OH]$. The viscosity and the density of the system were determined at temperatures of 100, 115 and 125°. Results of the measurements are presented in Fig. 8.

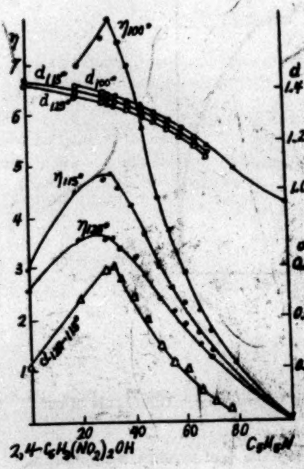

Fig. 8.

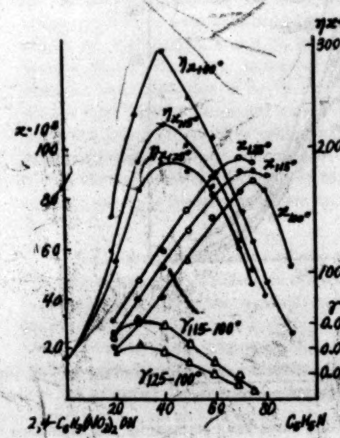

Fig. 9.

The isotherms of density, d, are represented by curves with considerable concavity to the composition axis, which attests to a greater contraction occurring in the given system than in the preceeding systems. The isotherms of viscosity, η, have a complicated form, being concave to the composition axis in the section of the curve close to 2,4-dinitrophenol, passing through a clearly-defined maximum, and convex to the composition axis in the section of curve close to pyridine. The maximum viscosity at 100° comes at 32.5 mole % of pyridine. With temperature increase it shifts slightly to the side of 2,4-dinitrophenol. The curves for the absolute temperature coefficient of viscosity, α, at temperatures 125-115° and at 125-100° have maxima close to 33 mole % of pyridine. The electroconductivity was investigated at the same temperatures. Results of the investigations are presented in Fig. 9.

The isotherms of the electroconductivity, κ, at 100° have maxima, corresponding to 75 mole % of pyridine, shifting to the side of 2,4-dinitrophenol with temperature increase. The curves for the relative temperature coefficient of electroconductivity, γ, have a maximum corresponding to 33 mole % of pyridine. The correction of electroconductivity for viscosity, $\eta\kappa$, shifts considerably the maximum to the side of 2,4-dinitrophenol; thus at a temperature of 100° the maximum comes at 39 mole % of pyridine, with increase in temperature the maximum is shifted to the side of pyridine. According to the viscosity and electroconductivity data on the liquid pyridine-2,4-dinitrophenol system, it can be concluded that the diagrams reflect a compound of the composition $C_5H_5N \cdot 2[2,4\text{-}C_6H_3(NO_2)_2OH]$.

SUMMARY

1. The systems formed between pyridine and each of the following: o-, p-nitrophenol and 2,4-dinitrophenol were investigated by the methods of fusibility, viscosity, density and electroconductivity.

2. The isotherms of viscosity, specific gravity, electroconductivity, reduced electroconductivity, and also the curves of temperature coefficients for the o-nitrophenol-pyridine system point to the formation in the liquid phase of a compound of the composition $C_5H_5N \cdot o\text{-}C_6H_4NO_2OH$.

3. By the method of fusibility, the formation of two compounds in the pyridine – p-nitrophenol system, of composition $C_5H_5N \cdot 2p\text{-}C_6H_4NO_2OH$ and $C_5H_5N \cdot p\text{-}C_6H_4NO_2OH$, was proven.

The isotherms of viscosity, electroconductivity, reduced electroconductivity, and also the curve of absolute temperature coefficient of viscosity, point to the existence of a compound, in the liquid phase, of the composition $C_5H_5N \cdot 2p\text{-}C_6H_4NO_2OH$.

4. The fusibility curve for the pyridine – 2,4-dinitrophenol system points to the formation of compounds in the solid phase of the composition

$$C_5H_5N \cdot 2[2,4\text{-}C_6H_3(NO_2)_2OH] \text{ and } C_5H_5N \cdot 2,4\text{-}C_6H_3(NO_2)_2OH.$$

The isotherms of viscosity, electroconductivity, reduced electroconductivity, and the curves of temperature coefficients, confirm the presence of a compound in the liquid phase, of the composition $C_5H_5N \cdot 2[2,4\text{-}C_6H_3(NO_2)_2OH]$.

5. Introduction of the nitro group into phenol promotes the formation of a chemical interaction with pyridine if the nitro group is situated in the p-position; the presence of the nitro group in the o-position inhibits interaction with pyridine, due to the o-effect action. Introduction of a second nitro group into the phenol molecule augments interaction with pyridine.

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SOME COMPOUNDS OF PYRIDINE WITH CUPRIC CHLORIDE

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Complex compounds of pyridine with salts of divalent copper have been the subject of investigation by many scientists. However, the number of compounds obtained remains comparatively small. Thus, for example, cupric chloride forms compounds of $CuCl_2 \cdot 2Pyr$, which give with hydrochloric acid a new product of the composition $CuCl_2 \cdot 2Pyr \cdot 2HCl$, crystallizing in the form of yellow prisms [1]. According to the data of Spero and Metyu [2], in the pyridine-cupric chloride system there come out three compounds in the solid phase: $CuCl_2 \cdot 2Pyr$, $2CuCl_2 \cdot 3Pyr$ and $CuCl_2 \cdot 6Pyr$. There are also indications of the existence of the compound $2CuCl_2 \cdot 3Pyr$ [3].

As the authors' experiments have shown, cupric chloride forms with pyridine a series of compounds, which have not been described up to the present, as far as is known through the literature, which is accessible to the authors. Upon interaction of cupric chloride with pyridine, in absolute alcohol or in dry acetone, the authors have obtained a compound of the composition $CuCl_2 \cdot Pyr$. For this purpose anhydrous cupric chloride and pyridine were taken in strictly equimolecular quantities. At first, upon addition of pyridine to a solution of cupric chloride in one of the indicated solvents, there is formed a blue compound, of the composition $CuCl_2 \cdot 2Pyr$, which subsequently converts into the compound $CuCl_2 \cdot Pyr$. Such a transformation occurs very slowly at room temperature. The reaction is accelerated considerably upon boiling in a flask equipped with reflux. The blue color then changes to grey. In acetone the reaction is complete after 2-3 hours, i.e., somewhat more rapidly than in absolute alcohol.

0.0982 g substance: 0.1315 g AgCl. 0.1166 g substance: 0.1553 g AgCl. 0.0960 g substance: 0.0289 g Cu. 0.1488 g substance: 0.0441 g Cu. 0.2721 g substance: 17.5 ml N_2 (23°, 716.5 mm); 0.2369 g substance: 14.3 ml N_2 (24°, 717.5 mm). Found %: Cl 33.04, 32.95; Cu 30.11, 29.64; N 6.79, 6.37. $CuCl_2 \cdot Pyr$. Calculated %: Cl 29.77; Cu 33.14; N 6.56.

The compound obtained interacts with mineral acids. With hydrochloric acid there is formed an equimolecular mixture of two compounds: $CuCl_2 \cdot 2Pyr \cdot 2HCl$, crystallizing in the form of yellow prisms, and $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$ — in the form of dark-brown. This reaction can likewise occur in the vapors of hydrochloric acid, but does not occur in an atmosphere of dry hydrogen chloride.

The reaction carried out in vapors of hydrochloric acid gave the following results: 0.2569 g and 0.3879 g of $CuCl_2 \cdot Pyr$ increased, respectively, in weight by 0.0523 and 0.0822 g. Assuming an equimolecular mixture is formed, the calculated increase in weight is equal to 0.0547 and 0.0826 g. Analysis of the reaction products likewise confirms the accuracy of such a conclusion.

0.4701 g mixture: 0.7831 g AgCl. 0.1117 g mixture: 0.0277 g Cu. Found %: Cl 41.17; Cu 24.80. Calculated %: Cl 41.07; Cu 24.54.

$CuCl_2 \cdot Pyr$ does not dissolve in organic solvents. It is decomposed into $CuCl_2 \cdot 2Pyr$ and $CuCl_2$ by water. Upon heating above 200° the compound gradually loses pyridine, transforming into anhydrous cuprous chloride. The decomposition temperature is 247-249°.

The compound of composition $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$ is obtained from an aqueous solution containing excess hydrochloric acid with exact stoichiometric quantities of cupric chloride and pyridine. If to the stoichiometric quantities of cupric chloride and pyridine there is added the exact calculated quantity of hydrochloric acid essential for formation of the indicated compound, from the resulting dark-green solution there will precipitate $CuCl_2 \cdot Pyr$ in the form of grey flakes. The addition of excess hydrochloric acid leads to solution of the dark-grey precipitate of $CuCl_2 \cdot Pyr$, and consequent concentration of the solution by boiling leads to precipitation of dark-brown crystals, of the composition $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$. The compound obtained can be purified by recrystallization from aqueous solution.

0.0405 g substance: 0.0693 g AgCl. 0.0879 g substance: 0.1505 g AgCl. 0.2047 g substance: 0.0559 g Cu; 0.2258 g substance: 0.0643 g Cu. 0.3524 g substance: 14.4 ml N_2 (24°, 732 mm). 0.3425 g substance: 12.2 ml N_2 (20.5°, 723 mm). 0.2052 g substance: 0.0179 g H_2O; 0.3432 g substance: 0.0280 g H_2O. Found %: Cl 42.30, 42.33; Cu 28.56, 28.35; N 4.32, 4.15; H_2O 8.72, 8.16. $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$. Calculated %: Cl 42.27; Cu 28.44; N 4.18; H_2O 8.15.

The compound obtained decomposes when dissolved in alcohol, with the formation of $CuCl_2 \cdot 2Pyr$, and in acetone with $CuCl_2 \cdot 2Pyr \cdot 2HCl$. It is insoluble in benzene, carbon tetrachloride, and similar solvents. It melts with decomposition at 194-195°.

The electroconductivity of the aqueous solution at 25° indicates that this compound dissociates into its component ions:

ν	125	250	500	1000	2000
μ	830.7	881.0	923.0	946.6	961.6

In the air $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$ gradually loses water and hydrogen chloride, transforming into the compound $3CuCl_2 \cdot 2Pyr$, a light-green powder. The compound $3CuCl_2 \cdot 2Pyr$ is not formed directly from cuprous chloride and pyridine. There results thermal decomposition of $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$.

0.0431 g substance: 0.0663 g AgCl. 0.1073 g substance: 0.1657 g AgCl. 0.2062 g substance: 0.0703 g Cu. 0.1212 g substance: 0.0413 g Cu. 0.4239 g substance: 18.2 ml N_2 (21°, 728.5 mm); 0.4912 g substance: 23.4 ml N_2 (22.5°, 723.5). Found %: Cl 38.18, 38.06; Cu 34.17, 34.08; N 4.93, 5.09. $3CuCl_2 \cdot 2Pyr$. Calculated %: Cl 37.88; Cu 33.95; N 4.98.

In water $3CuCl_2 \cdot 2Pyr$ decomposes with the formation of $CuCl_2 \cdot 2Pyr$. It does not dissolve in organic solvents. It is soluble in acids. With hydrochloric acid it gives a compound $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$. It is stable in air. Upon heating above 100°, it decomposes with the formation of cupric chloride. It melts with decomposition at 272-273°.

The compound with six molecules of pyridine $CuCl_2 \cdot 6Pyr$ was obtained by the action of considerable pyridine excess upon anhydrous cupric chloride. At first there is formed the compound $CuCl_2 \cdot 2Pyr$, and subsequently, after about ten days, if the temperature does not exceed 12-15°, there results a compound of the composition $CuCl_2 \cdot 6Pyr$, dark blue in color. Upon cooling to −10°, and lower, the formation of $CuCl_2 \cdot 6Pyr$ occurs much more rapidly. The compound is stable in pyridine solution at a temperature not over 15°, while according to the literature data it is stable only at −10°. It decomposes in the air with the formation of $CuCl_2 \cdot 2Pyr$.

0.4508 g $CuCl_2 \cdot 6Pyr$ loss in weight 0.2342 g. For a loss of 4 pyridine molecules, the calculated weight loss is 0.2343 g.

0.1003 g substance: 0.0456 g AgCl. 0.4204 g substance: 0.1988 g AgCl. 0.4508 g substance: 0.0450 g Cu. 0.2550 g substance: 0.0261 g Cu. Found %: Cl 11.25, 11.43; Cu 9.98, 10.24. $CuCl_2 \cdot 6Pyr$. Calculated %: Cl 11.65; Cu 10.44.

SUMMARY

1. Upon interaction of cupric chloride with pyridine in absolute alcohol or dry acetone, there is formed a compound of the composition $CuCl_2 \cdot Pyr$.

2. Upon interaction of stoichiometric quantities of cupric chloride and pyridine in hydrochloric acid solutions, there is formed a compound of the composition $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$.

3. It was demonstrated that upon thermal decomposition of the compound $3CuCl_2 \cdot 2Pyr \cdot 2HCl \cdot 2H_2O$ there is formed the compound $3CuCl_2 \cdot 2Pyr$.

4. The compound $CuCl_2 \cdot 6Pyr$, known in the literature, is stable at temperatures not exceeding 15°.

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INVESTIGATIONS IN THE FIELD OF REDOX TRANSFORMATIONS

I. POLAROGRAPHIC INVESTIGATION OF 1-CHLOROBUTANONE-2, 3-CHLOROBUTANONE-2, PROPIONYLCARBINOL AND METHYLACETYLCARBINOL

M. I. Bobrova and N. S. Tikhomirova

The works of Winkel and Proske are devoted to the reduction of hydroxycarbonyl compounds, and in particular, to methylacetylcarbinol (acetoin) in 0.1 N NH_4Cl, at the dropping mercury electrode.

The authors determined the so-called "decomposition potential". For methylacetylcarbinol it was found to be equal to −1.7 V at a concentration of 10^{-3} M/liter.

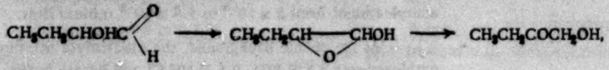
Tachi [3] determined the decomposition potential of methylacetylcarbinol according to the tangential method in acid medium and found it equal to −1.14 V.

The authors mentioned limited themselves to the determination of redox potentials at one given concentration. They did not determine the value for the polarographic constant nor the electron discharge upon reduction of 1 mole of substance.

M. I. Bobrova and P. N. Sokolov [4] have made polarograms of 1-chlorobutanone-2 and 3-chlorobutanone-2 in media of 0.01 N HCl, 0.01 N KCl and in 80% ethanol for the sole purpose of determining half-wave potentials.

S. N. Danilov, E. D. Venus-Danilova and V. F. Kazimirova have demonstrated in their multiple investigations that hydroxyaldehydes can give isomeric secondary keto-alcohols in acid or alkaline medium.

Diphenylglycolic [5], benzylglycolic [6], alpha-hydroxyisobutyric [7], dicyclohexylglycolic [8], alpha-hydroxyhexahydrobenzoic [9], alpha-hydroxybutyric [10] and alpha-hydroxyenanthic [11] aldehydes were isomerized into the corresponding secondary ketoalcohols. In no case was a primary ketoalcohol obtained whose formation was to be expected using the alcohol-oxidizing schemes of Favorsky. Thus, for instance, the formation of propionylcarbinol from α-hydroxybutyric aldehyde would be expected



$$CH_3CH_2CHOHC(=O)H \longrightarrow CH_3CH_2\underbrace{CH\text{—}CHOH}_{O} \longrightarrow CH_3CH_2COCH_2OH,$$

but in practice methylacetylcarbinol was obtained.

There arose the question of whether or not propionylcarbinol is the intermediate product in the isomerization of α-hydroxybutyric aldehyde to methylacetylcarbinol. For this purpose it was necessary to verify the possibility of transformation of propionylcarbinol into methylacetylcarbinol under analogous conditions. Such experiments have been carried out by S. N. Danilov and N. S. Tikhomirova, starting with the same ketoalcohol and its corresponding chloroketone of 1-chlorobutanone-2 [12]. For study of this problem we have turned to the method of polarography which, it seemed, would give the opportunity of: 1) determining each of the named substances individually or in their mixture resulting from reaction; 2) allowing conclusions about the transformation possibility of the primary ketoalcohol to the secondary from the obtained half-wave potentials of these substances, of their polarographic constants, and of the electron consumption upon reduction of 1 mole of the substance.

Kern [13] made use of certain hydroxycarbonyl compounds in the role of polymerization initiators. We assume that the polarographic method can give indication as to which one of the ketoalcohols will prove to be more active under the conditions of polymerization.

EXPERIMENTAL

The chloroketones and ketoalcohols were synthesized as described earlier [12], and possessed the constants indicated in Table 1.

TABLE 1

Substance	Boiling point	d_4^{20}	n_α^{20}	n_D^{20}	MR_D found	MR_D calculated
1-Chlorobutanone-2	137-138°	1.0850	1.4311	–	25.42	25.42
3-Chlorobutanone-2	116-117	1.05705	1.4210	–	25.55	25.42
Propionylcarbinol	78° (60 mm)	1.0264	–	1.4248	22.04	22.21
	54 (18 mm)			1.4248		
Methylacetylcarbinol	38 (12 mm)	1.0101	–	1.4200	22.04	22.21
	40 (13 mm)			1.4197		
Methylacetylcarbinol dimer *	–	–	–	–	–	–

Methylacetylcarbinol dimer was obtained after double distillation in vacuo of the ketoalcohol, and had a melting point as indicated in the literature [14].

The polarography was carried out in a Gorky ("Etalon" factory) polarograph M-7, with a mirror galvanometer, whose sensitivity on a scale length of 100 centimeters is equal to 175 mm/μA. For the work, shunts were used from 1/5 to 1/200 of the current sensitivity.

The polarography was conducted in an electrolyzer, pictured in Fig. 1. On the left is located the current outlet from the anode, and on the right a tube with stopcock, which is utilized for measuring the potential of the bottom and the pH of the solution under study, and likewise a tube for conducting hydrogen for the purpose of removing dissolved oxygen from the solution.

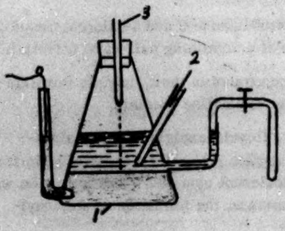


Fig. 1. Electrolyzer
1) mercury anode; 2) tube for hydrogen conduction; 3) capillary.

Capillary characteristic:. mass of the mercury drop = 0.0025 g, dropping period = 3.75 sec. Resistance of the solutions studied, R ≃ 3000 ohms. Primary and secondary chloroketones were studied in the concentration range from 1 x 10^{-3} to 2.8 x 10^{-2} moles/liter, the propionylcarbinol from 1.2 x 10^{-2} to 3 x 10^{-2} moles/liter, and the methylacetylcarbinol from 5 x 10^{-3} to 1.8 x 10^{-2} moles/liter.

As the phonic background, the electrolyte mixture employed was 0.1 N KCl, 0.1 N NH_4Cl and borate buffer with pH = 10.0. All half-wave potential values ($E_{1/2}$) are referred to the saturated calomel electrode potential with correction for iR.

The polarographic results for 1-chlorobutanone-2 in 0.1 N NH_4Cl solution are presented in Fig. 2.** From examination of the polarograms, it is apparent that upon reduction of 1-chlorobutanone-2 at the dropping mercury electrode in 0.1 N NH_4Cl, there is only one polarographic wave. The half-wave ($E_{1/2}$) potential found graphically at $i_d/2$ with a correction for iR is equal to −1.104V. The value $E_{1/2}$ found at

$$\log \frac{i}{i_d - i} = 0,$$ is −1.09. The polarographic constant (i_d/C) i.e. the diffusion current with regard to unit concentration = 1614 μA/g. The dependence of $\log \frac{i}{i_d - i}$ upon E is presented in Fig. 3. The number of electrons participating in the reduction of

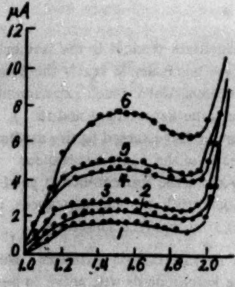


Fig. 2. Polarograms of 1-chlorobutanone-2 in 0.1 N solution of NH_4Cl (20 ml). Weighed portions (g): 1) 0.0112, 2) 0.0116, 3) 0.0204, 4) 0.0240, 5) 0.0282, 6) 0.0410.

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* M.p. 95.5°.

** On all polarograms the diffusion current values are quoted 10 times smaller than the actual.

1 mole of the substance (α) [15] (which is apparent in the case of a non-reversible reduction) is determined from the wave equation by the tangent of the inclination angle of the straight line $\log \frac{i}{i_d - i}$ to E, namely

at t = 15°

$$E = E_{1/2} - \frac{0.057}{\alpha} \log \frac{i}{i_d - i};$$

from which

$$\alpha = 0.057 \frac{\Delta \log \frac{i}{i_d - i}}{\Delta E} = 0.513.$$

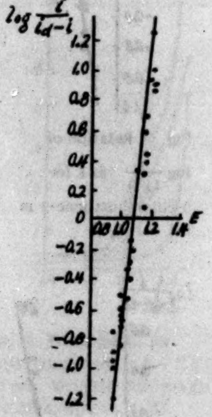

Fig. 3. Relation of $\log \frac{i}{i_d - i}$ to E for 1-chlorobutanone-2 in 0.1 N NH_4Cl.

The polarographic results for 1-chlorobutanone-2 in borate buffer solution at pH = 10.0 are presented in Fig.4. From examination of the polarograms, it is apparent that the reduction of 1-chlorobutanone-2 in buffer solution is likewise accompanied by the formation of one polarographic wave with $E_{1/2} = -1.087$ V, by the graphic. method of determination of potential, i.e. at $i_d/2$.

In the instance $\log \frac{i}{i_d - i} = 0$, $E_{1/2} = -1.110$ V.

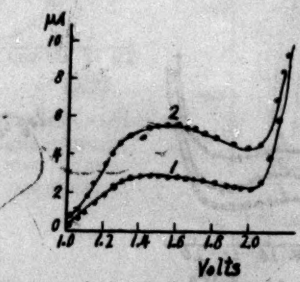

Fig. 4. Polarograms for 1-chlorobutanone-2 in buffer solution at pH = 10.0 (20 ml). Weighed portions (g): 1) 0.0130, 2) 0.0268.

The polarographic constant (i_d/C) for 1-chlorobutanone-2 at pH = 10.0 is equal to 1720 μA/g. The relation between $\log \frac{i}{i_d - i}$ and E is presented in Fig. 5.

The polarographic results for 3-chlorobutanone-2 in 0.1 N NH_4Cl are presented in Fig.6. It is apparent from the polarograms that the half-wave potential of 3-chlorobutanone-2 in 0.1 N NH_4Cl = 1,044 V. The polarographic constant i_d/C = 1075 μA/g. The relation $\log \frac{i}{i_d - i}$ to E is presented in Fig. 7. The value of $\alpha = 0.353$.

The polarographic results for 3-chlorobutanone-2 in borate buffer solution at pH = 10.0 are presented in Fig.8. It is apparent from the polarograms that upon reduction of 3-chlorobutanone-2 at pH = 10.0, there is formed a wave whose half-wave potential at $i_d/2 = -1.049$ V, and at $\log \frac{i}{i_d - i} = 0$, the value for $E_{1/2} = -1.080$ V. The polarographic constant i_d/C = 1071 μA/g. The relation of $\log \frac{i}{i_d - i}$ to E is represented in Fig. 9. The value for $\alpha = 0.285$.

The polarographic results for propionylcarbinol in 0.1 N KCl are represented in Fig. 11. It is apparent from examination of the polarograms that upon reduction of propionylcarbinol in 0.1 N KCl, there occurs one wave from which $E_{1/2}$ found at $i_d/2$ is equal to −1.772 V, and at $\log \frac{i}{i_d - i} = 0$ is equal to −1.81 V. The polarographic

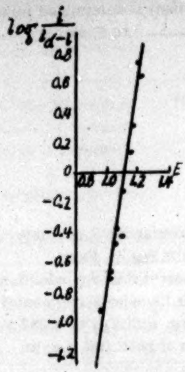

Fig. 5. Relation of log $\frac{i}{i_d-i}$ to E for 1-chlorobutanone-2 in buffer solution at pH = 10.0

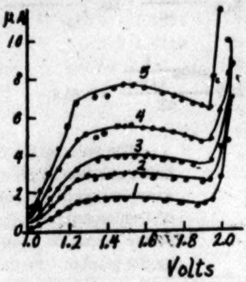

Fig. 6. Polarograms for 3-chlorobutanone-2 in 0.1 N NH_4Cl (20 ml). Weighed portions (g): 1) 0.0124, 2) 0.0234, 3) 0.0312, 4) 0.0413, 5) 0.0601.

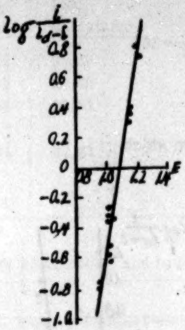

Fig. 7. Relation of log $\frac{i}{i_d-i}$ to E for 3-chlorobutanone-2 in 0.1 N NH_4Cl.

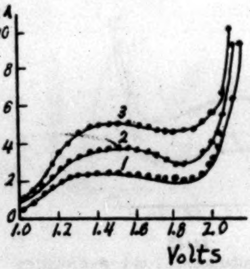

Fig. 8. Polarograms of 3-chlorobutanone-2 in buffer solution at pH = 10.0 (20 ml). Weighed portions (g): 1) 0.0210, 2) 0.0306, 3) 0.0426.

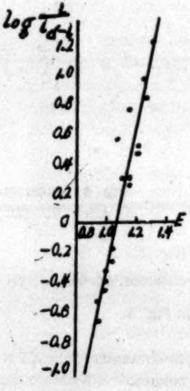

Fig. 9. Relation of log $\frac{i}{i_d-i}$ to E for 3-chlorobutanone-2 in buffer solution at pH = 10.0

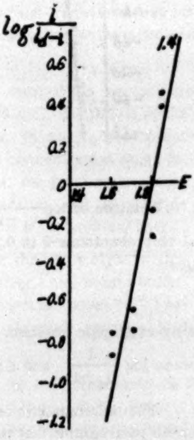

Fig. 10. Relation of log $\frac{i}{i_d-i}$ to E for propionylcarbinol in 0.1 N KCl.

constant (i_d/C) for propionylcarbinol was found to be equal to 919 μA/g. The relation of log $\frac{i}{i_d-i}$ to E is represented in Fig. 10. The value for α = 0.29.

The polarography of propionylcarbinol in borate buffer solution at pH = 10.0 gave no waves. This indicates that propionylcarbinol at pH = 10.0 is not reduced. The polarographic results for methylacetylcarbinol in 0.1 N NH_4Cl are represented in Table 12. From examination of the polarograms it is apparent that upon reduction of methylacetylcarbinol in 0.1 N NH_4Cl there occurs one polarographic wave, the half-wave value for which ($E_{1/2}$) at $i_d/2$ is equal to −1.684 V, and upon log $\frac{i}{i_d-i}$ = 0 is equal to −1.82 V. The polarographic constant i_d/C = 5097 μA/g. The relation of log $\frac{i}{i_d-i}$ to E is represented in Fig. 13. The value of α = 0.47.

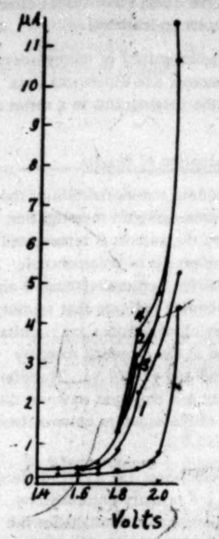

Fig. 11. Polarograms for propionylcarbinol in 0.1 N KCl (20 ml). Weighed portions(g): 1) 0.0214, 2) 0.0334, 3) 0.0334, 4) 0.0401.

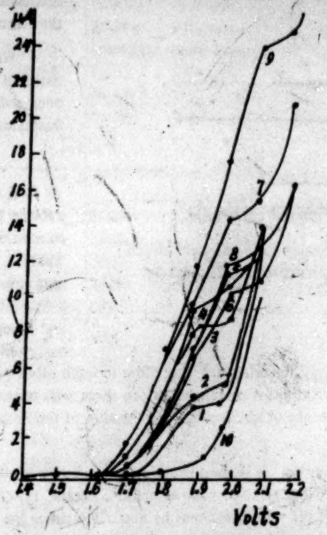

Fig. 12. Polarograms for methylacetylcarbinol in 0.1 N NH_4Cl (20 ml). Weighed portions(g) 1) 0.0088, 2) 0.0090, 3) 0.0148, 4) 0.0174, 5) 0.0207, 6) 0.0252, 7) 0.0304, 8) 0,0314, 9) 0.426, 10) ground.

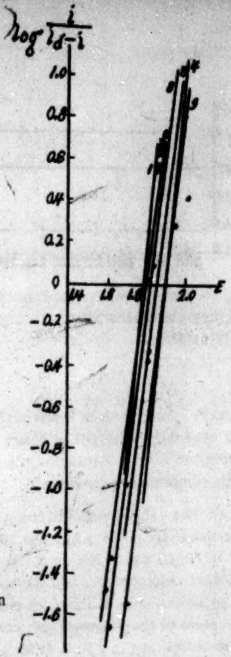

Fig. 13. Relation of $\log\frac{i}{i_d-i}$ to E for methylacetylcarbinol in 0.1 N NH_4Cl.

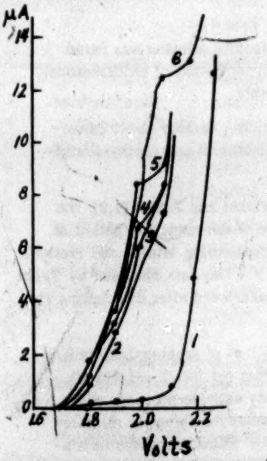

Fig. 14. Polarograms for methylacetylcarbinol in buffer solutions at pH = 10.0 (20 ml). Weighed portions (g): 1) ground, 2) 0.0250, 3) 0.0257, 4) 0.0334, 5) 0.0426, 6) 0.0593.

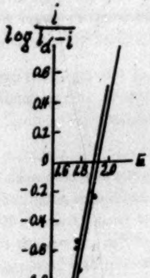

Fig. 15. Relation of $\log\frac{i}{i_d-i}$ to E for methylacetylcarbinol at pH = 10.0.

The polarographic results for methylacetylcarbinol in borate buffer solution at pH = 10.0 are presented in Fig. 14.

The relation $\log\frac{i}{i_d-i}$ to E for methylacetylcarbinol at pH = 10.0 is represented in Fig. 15. The value for α = 0.32.

The relation of $E_{1/2}$ to concentration for propionylcarbinol and methylacetylcarbinol is represented in Fig. 16.

The reduction of methylacetylcarbinol dimer at the dropping mercury cathode takes place analogously to

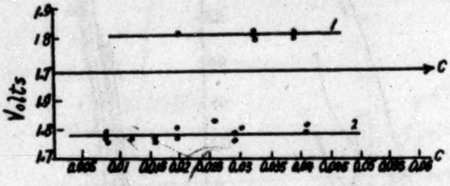

Fig. 16. Relation of $E_{1/2}$ to concentration for propionylcarbinol and methylacetylcarbinol. 1) propionylcarbinol, 2) methylacetylcarbinol.

the reduction of methylacetylcarbinol. The half-wave potential and the polarographic constant for the dimer have values close to that of methylacetylcarbinol.

With polarography of methylacetylcarbinol monomer and dimer, maxima occurred in the polarograms in a series of instances.

Evaluation of Results

A complete summarization of the data on the polarographic investigation carried out by the authors is represented in Table 2. The results of polarographic measurements for 1-chlorobutanone-2 and 3-chlorobutanone-2 indicate that primary and secondary chloroketones are simultaneously reduced at the dropping mercury electrode, since their half-waves ($E_{1/2}$) potentials are very close to each other (−1.066 and −1.077 V). Therefore, their qualitative analysis in binary mixtures is impossible, since there will occur only one common wave on the polarogram of such a mixture, the height of which should be the sum of the heights of the separate chloroketone waves composing the mixture.

The value for the diffusion current, as related to the unit mass of reducible substance, i.e. i_d/C, differs quite markedly (1614 μA/g and 1075 μA/g). The polarographic constant, i_d/C for the primary chloroketone, both in NH_4Cl and in borate buffer at pH = 10.0, exceeds by about 1.5 times the polarographic constant for the secondary chloroketone, and the apparent electron consumption for one mole of reducible substance (α) is greater by the same number for primary chloroketones as over and above that for the secondary chloroketone. The values of the polarographic constant for primary chloroketone in solutions of ammonium chloride, and in borate buffer, at pH = 10.0 differ very little in magnitude. The same can be said for the polarographic constant of secondary chloroketone. It does not change in value in going from ammonium chloride solution to borate buffer at pH = 10.0. Thus, transition from a weak acid medium to an alkaline medium did not show any effect on the character of the chloroketone reductions.

As a result of the data obtained for the chloroketones investigated, a satisfactory relation was found between the diffusion current value, or in other words the wave height, and the concentration of chloroketones, Thus the qualitative determination of the individual chloroketones was made possible.

The electron consumption for 1 mole of substance was expressed as a fractional number in all cases. This indicates that reduction of 1-chlorobutanone-2, 3-chlorobutanone-2, propionylcarbinol and methylacetylcarbinol at the dropping mercury electrode proceeds irreversibly.

Comparing experimental data for methylacetylcarbinol with the data of Winkel and Proske [1,2], the authors have noted that if one and the same method is employed for determination of the reduction potential, there will be good agreement of results. The reduction potential found by the authors, using Winkel and Proske's method, is equal to −1.69 V, which Winkel and Proske found to be equal to −1.70 V. The data obtained by Tachi [3] are considerably more positive than those of the authors and of Winkel and Proske, even after discounting the pH difference for the media and the method for the determination of the value.

From a comparison of the polarographic data of methylacetylcarbinol with that of propionylcarbinol, it follows that the half-wave potentials of these substances are very close to one another (−1.743 V, −1.791 V), which indicates that the display of their reactive capacities at the dropping mercury cathode proceeds under the same conditions; in other words, the reduction of methylacetylcarbinol and propionylcarbinol in mixtures of one with the other, start at one and the same potential drop, i.e., simultaneously. Polarograms for such a mixture should have one wave common for the methylacetylcarbinol and propionylcarbinol, the height of which is equal to the sum of the wave heights of these two components.

It follows from the data obtained, that in the case of methylacetylcarbinol and propionylcarbinol the

TABLE 2

Expt. nos. in order	Name of substance and the phonic (background) electrolyte (20 ml)	Weighed portion (g)	Diffusion current i_d (in μA)	Polarographic constant i_d/C $\left(\text{in } \frac{\mu A}{g}\right)$	Half-wave potential ($E_{1/2}$) with respect to the saturated calomel electrode (in volts)			Average value for $E_{1/2}$ (in volts)	Average value for i_d/C $\left(\text{in } \frac{\mu A}{g}\right)$	Electron discharge for one mole of the substance α
					at $\frac{i_d}{2}$	with correction for iR	at $\log\frac{i}{i_d - i} = 0$			
1	1-chlorobutanone-2 in 0.1 N NH_4Cl	0.0112	13.0	–	–	–	–			
2		0.0116	19.9	1715	−1.100	−1.070	−1.09	−1.066	1614	0.513
3		0.0204	33.3	1636	−1.112	−1.055	−1.09			
4		0.0240	39.4	1642	−1.095	−1.036	−1.09			
5		0.0282	43.4	1540	−1.102	−1.037	−1.09			
6		0.0410	63.5	1539	−1.140	−1.045	−1.09			
1	1-chlorobutanone-2 in buffer solution at pH = 10.0.	0.0130	22.9	1761	−1.140	−1.106	−1.11	−1.098	1720	0.399
2		0.0268	45.0	1680	−1.135	−1.067	−1.11			
1	3-chlorobutanone-2 in 0.1 N NH_4Cl	0.0124	13.7	1105	−1.120	−1.099	−1.11	−1.077	1075	0.353
2		0.0234	25.5	1089	−1.123	−1.087	−1.11			
3		0.0312	33.2	1064	−1.119	−1.069	−1.11			
4		0.0431	45.2	1048	−1.080	−1.012	−1.11			
5		0.0601	64.3	1070	−1.120	−1.024	−1.11			
1	3-chlorobutanone-2 in buffer solution at pH = 10.0.	0.0210	20.9	995	−1.075	−1.044	−1.08	−1.064	1071	0.285
2		0.0306	34.6	1130	−1.100	−1.048	−1.08			
3		0.0426	46.2	1089	−1.125	−1.056	−1.08			
1	Propionylcarbinol in 0.1 N KCl	0.0214	19.6	925	−1.81	−1.780	−1.81	−1.791	919	0.290
2		0.0334	31.2	934	−1.82	−1.770	−1.81			
3		0.0334	29.3	876	−1.82	−1.770	−1.81			
4		0.0401	37.6	939	−1.825	−1.769	−1.80			
1	Methylacetylcarbinol in 0.1 N NH_4Cl	0.0088	39.8	4391	1.80	−1.740	−1.79	−1.743	5097	0.47
2		0.0090	48.0	5333	−1.80	−1.728	−1.77			
3		0.0148	86.8	5865	−1.80	−1.670	−1.79			
4		0.0174	98.4	5655	−1.80	−1.652	−1.79			
5		0.0207	114.0	5507	−1.85	−1.679	−1.87			
6		0.0252	103.6	4118	−1.87	−1.715	−1.82			
7		0.0304	148.0	4869	−1.85	−1.628	−1.84			
1	Methylacetylcarbinol in buffer solution at pH = 10.0	0.0250	52.8	2112	−1.89	−1.811	1.90	−1.853	2112	0.320
2		0.0257	61.4	2236	−1.89	−1.795	–			
3		0.0334	67.2	1892	−1.89	−1.789	–			
4		0.0426	84.8	1989	−1.94	−1.813	1.92			
5		0.0593	128.6	2339	−1.97	−1.777	–			

existence of a satisfactory relation between the height of the wave and the concentration was likewise found. Consequently, there exists the possibility of quantitative analysis for the two ketoalcohols, separately, which are present.

The polarographic constants for these two substances differ considerably from one another, namely i_d/C for methylacetylcarbinol is approximately 5 times greater than that for propionylcarbinol under analogous conditions (5097 and 919 $\mu A/g$). The apparent consumption of electrons for 1 mole of reducible substance for methylacetylcarbinol is likewise 1.62 times higher than that for propionylcarbinol. With an increase in pH, the value for the polarographic constant drops for methylacetylcarbinol, because its capacity for reduction in alkaline medium is less.

The effect of pH on the medium is apparent for ketoalcohol reduction, which was not observed for the chloroketone reductions. Propionylcarbinol is not reduced at pH = 10, and methylacetylcarbinol reduction proceeds less readily than in weak acid medium (Table 2). This is explained by the fact that alcoholic groups are easily oxidized in alkaline medium.

From a comparison of the polarographic data of propionylcarbinol and methylacetylcarbinol with the polarographic data of their corresponding chloroderivatives, i.e., 1-chlorobutanone-2 and 3-chlorobutanone-2, it follows that the polarographic constant (i_d/C) for the primary ketoalcohol is smaller than that of the secondary, while at the same time the polarographic constant for its corresponding primary chloroketone is larger, on the other hand, than for the secondary chloroketone. The apparent electron consumption for the primary chloroketone likewise exceeds the value, α, of the secondary chloroketone, for both polarography in 0.1 N NH_4Cl solution, and in borate buffer at pH = 10.0 by about 1.5 times. But for the corresponding primary ketoalcohol the value, α, is smaller than the value, α, for the secondary ketoalcohol, likewise by about 1.5 times. Thus, the polarographic behavior of the primary ketoalcohol, in comparison with the secondary, is directly opposite to that which takes place under the given conditions for the corresponding primary chloroketones in comparison with the secondary.

The polarographic data obtained are in agreement with the experimental data of S. N. Danilov and N. S. Tikhomirova [12], according to which 1-chlorobutanone-2 transforms, under the conditions of alkaline medium, not into the corresponding, but into the isomeric ketoalcohol, namely in the methylacetylcarbinol, at the same time that propionylcarbinol, under these conditions, does not undergo hydroxyketone transformation into the isomeric ketoalcohol. It is possible, in the case of chloroketone, that transformation proceeds in the following manner: 1-chlorobutanone-2 ⟶ 3-chlorobutanone-2 ⟶ methylacetylcarbinol.

The transformation of α-hydroxybutyric aldehyde into methylacetylcarbinol, through the propionylcarbinol, is not very likely on the basis of the polarographic data.

The authors express their indebtedness to S. N. Danilov for his constant interest in the work, and for his many valuable suggestions.

SUMMARY

1. The half-wave potentials ($E_{1/2}$), the polarographic constants (i_d/C), the relation of $\log\frac{i}{i_d-i}$ to E, the apparent consumption of electrons for 1 mole of reducible substance, (α), for 1-chlorobutanone-2, 3-chlorobutanone-2, propionylcarbinol and methylacetylcarbinol in the concentration range $1\cdot10^{-3}$ to $1\cdot10^{-2}$ moles/liter in 0.1 N NH_4Cl and in borate buffer solution at pH = 10,0, have been determined.

2. On the basis of proportionality between wave height and concentration of 1-chlorobutanone-2, 3-chlorobutanone-2, propionylcarbinol and methylacetylcarbinol, the feasibility for their qualitative and quantitative determination, separately, by the polarographic method was determined.

3. On the basis of polarographic data, it can be assumed that propionylcarbinol under the conditions used does not transform into methylacetylcarbinol.

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INVESTIGATIONS IN THE FIELD OF REDOX TRANSFORMATIONS

II. POLAROGRAPHIC INVESTIGATION OF BENZOIN, BENZIL, DIACETYL AND ETHYLGLYOXAL

M. I. Bobrova and N. S. Tikhomirova

In the preceding article [1], the authors examined the polarographic characteristics of ketoalcohols belonging to the aliphatic series – propionylcarbinol, $CH_3CH_2COCH_2OH$ and methylacetylcarbinol, $CH_3CHOHCOCH_3$. In the syntheses of these compounds, or in the transformations of these compounds, S. N. Danilov and N. S. Tikhomirova were concerned with their partial oxidation into the corresponding dicarbonyl compounds. It was therefore of interest to know the polarographic characteristics of ethylglyoxal and diacetyl: CH_3CH_2COCHO and $CH_3COCOCH_3$.

For comparison with the aliphatic compounds, at the suggestion of S. N. Danilov, we have studied the redox capacity of aromatic ketoalcohols and diketones: benzoin $C_6H_5COCHOHC_6H_5$ and benzil $C_6H_5COCOC_6H_5$, into which benzoin is easily oxidized, as observed by S. N. Danilov [2].

A series of works has been devoted to the reduction of hydroxycarbonyl compounds at the dropping mercury electrode. Tachi [3] determined the redox potential for benzoin in a medium of 0.01 N HCl +0.1 N KCl by the tangent method. Relative to the normal calomel electrode at a concentration of 10^{-4} moles/liter it was found to be equal to –0.953 V. Semerano [4] determined the so-called "molar reduction potential" of benzoin, i.e., the potential at which reduction of benzoin at 1 mole/liter concentration is initiated. According to Semerano's data, it is equal to –1.06 V in 0.1 N NH_4Cl at 50% ethanol. Winkel and Proske [5,6] have determined by extrapolation of the Le Blanc current to zero, the reduction potential value, the so-called "decomposition potential", of benzoin in 0.1 N NH_4Cl solution is equal to –1.22 V. Adkins and Cox [7] determined the reduction potential of benzoin in 0.2 N tetramethylammonium hydroxide solution. Two waves with potentials of –0.7 and –1.4 V were found.

The reduction potential of benzil was found by Tachi to be –0.203 V in 0.01 N HCl + 0.1 N KCl at pH 2, and was found by Winkel and Proske to have the potentials –0.019 and –0.586 V in 0.1 N NH_4Cl solution. The half-wave potentials for benzil in 0.2 N tetramethylammonium hydroxide solution are equal to –0.65 and 1.4 V according to the data of Adkins and Cox. As was indicated by Winkel and Proske, diacetyl in 0.1 N NH_4Cl solution likewise gives two waves of approximately the same height. The reduction potential for the first is equal to –0.7 V, and for the second, –1.58 V; and in 0.1 N LiCl solution, –0.81 and –1.93 V, respectively. Winkel and Proske have found the reduction potential in a medium of 0.01 N HCl + 0.1 N KCl to be equal to –0.4 V; likewise, Tachi found an analogous value for the diacetyl reduction potential in 0.01 N HCl + 0.1 N KCl solution medium, using the tangential method. But this is only an apparent agreement of results, since their methods for determining potentials were different. The reduction of ethylglyoxal was not studied polarographically.

Data obtained by various authors for redox potentials are very inconsistent, as can be seen from this brief review of the works on polarographic reduction of hydroxycarbonyl compounds. They did not determine any of the polarographic constants nor the electron consumption per mole of reducible substance.

EXPERIMENTAL

Work objectives and method of measurements. The benzoin had a m.p. of 133°, benzil – m.p. 95°, diacetyl – b.p. 87-89°, n_D^{18} 1.3933, as indicated in the literature [8]. The ethylglyoxal was obtained by synthesis from propionylcarbinol with the characteristics: b.p, 110° at 135 mm, n_D^{20} 1.4178, which was in agreement with the literature data [9].

Benzoin and benzil were studied in the concentration range: first, from $1 \cdot 10^{-3}$ to $1,2 \cdot 10^{-3}$ moles/liter, and second, from $2.13 \cdot 10^{-3}$ to $8.6 \cdot 10^{-3}$ moles/liter, diacetyl from $4 \cdot 10^{-3}$ to $6.5 \cdot 10^{-3}$ moles/liter, and ethylglyoxal from $2.2 \cdot 10^{-3}$ to $5.5 \cdot 10^{-3}$ moles/liter.

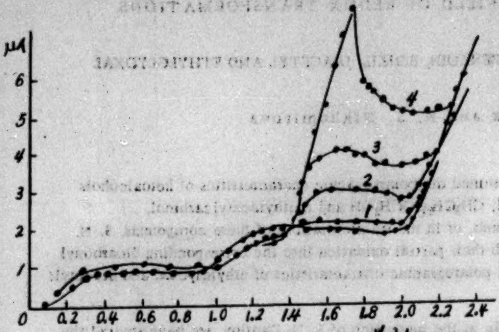

Fig. 1. Benzoin polarograms in 0/02 N NH_4Cl at 78 % C_2H_5OH (20 ml). Weighed portions (g): 1) 0.0043, 2) 0.0156, 3) 0.0276, 4) 0.0476.

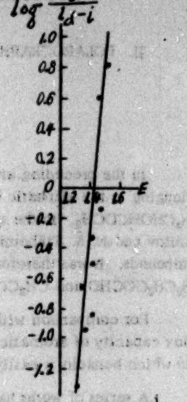

Fig. 2. Relation of log $\frac{i}{i_d-i}$ to E for benzoin in 0.02 N NH_4Cl at 78% C_2H_5OH.

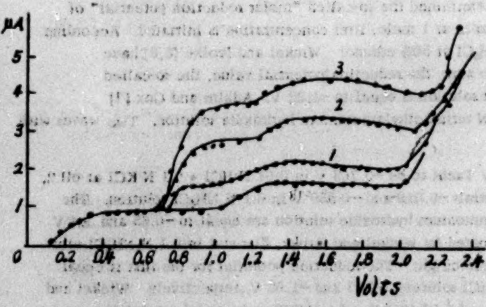

Fig. 3. Polarograms for benzil in 0.02 N NH_4Cl at 78% C_2H_5OH (20 ml). Weighed portions (g): 1) 0.0090, 2) 0.0238, 3) 0.0238.

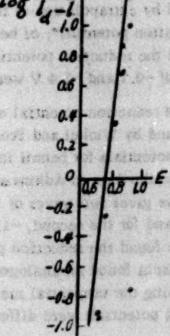

Fig. 4. Function log $\frac{i}{i_d-i}$ versus E for benzil in 0.02 N NH_4Cl at 78% C_2H_5OH.

As phonic backgrounds, the electrolytes employed were 0.02 N NH_4Cl in 78% C_2H_5OH and 0.1 N NH_4Cl.

Polarography was conducted on a Gorky (factory "standard") polarograph M-7 with a mirror galvanometer, the sensitivity of which is equal to 175 mm/μA on a scale distance of 100 centimeters from the mirror. In the work, shunts from 1/5 to 1/200 of the current sensitivity were used. In all of the experiments an electrolyzer was used, with an internal anode whose potential was regularly determined with reference to the calomel electrode, with the aid of a Rapp's potentiometer. The capillary characteristic: mass of the mercury drop = 0.0025 g, dropping period = 3.75 sec. From this capillary constant $L \doteq m^{\frac{2}{3}} \cdot \tau^{\frac{1}{6}} = 0.956 \text{ mg}^{\frac{2}{3}} \text{ sec.}^{-\frac{1}{2}}$. The resistance of the solutions studied was ~3000 ohms. All half-wave values ($E_{1/2}$) are referred to the saturated calomel electrode potential with correction for iR.

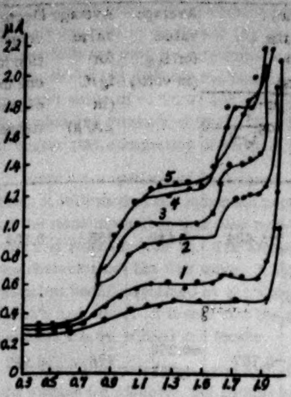

Fig. 5. Polarograms for diacetyl in 0.1 N NH_4Cl. Weighed portions (g): 1) 0.0217, 2) 0.715, 3) 0.0877, 4) 0.1127, 5) 0.1127.

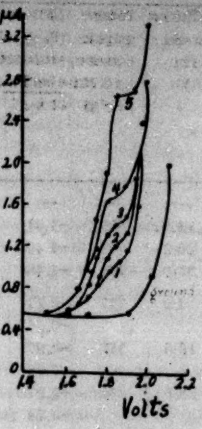

Fig. 6. Polarograms for ethylglyoxal in 0.1 N NH_4Cl (20 ml) Weighed portions (g): 1) 0.0039, 2) 0.0049, 3) 0.0060, 4) 0.0082, 5) 0.0094.

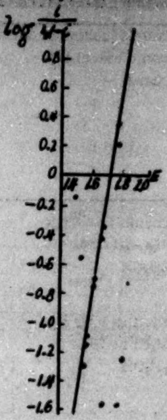

Fig. 7. Relation of $\log \frac{i}{i_d - i}$ to E for ethylglyoxal in 0.1 N NH_4Cl.

The polarographic results for benzoin are presented in Fig. 1.* As follows from the data obtained, the reduction of benzoin at the dropping mercury electrode is accompanied by the appearance of one wave with a half-wave potential at $i_d/2 = -1.407$ V, and at $\log \frac{i}{i_d - i} = 0$ $E_{1/2} = -1.434$ V.

The value $E_{1/2}$, increases as the benzoin concentration increases. The benzoin polarographic constant, i.e., the diffusion current, referred to unit concentration, is equal to 735 μ A/g. The function $\log \frac{i}{i_d - i}$ with respect to E is presented in Fig.2. The apparent number of electrons participating in the reduction of 1 mole of substance in the case of an irreversible process [10], is determined from the tangent for the angle of inclination of the straight line, $\log \frac{i}{i_d - i}$ versus E, namely: at 15° $E = E_{1/2} - \frac{0.057}{a} \log \frac{i}{i_d - i}$

$$a = 0.057 \cdot \Delta \frac{\log \frac{i}{i_d - i}}{\Delta E}.$$

The value, a, for benzoin upon its reduction in 0.02 N NH_4Cl at 78 % C_2H_5OH is equal to 0.655 (Fig. 2).

The results of benzil polarography in 0.02 N NH_4Cl at 78% C_2H_5OH are presented in Fig.3. As can be seen from the polarograms, there appear two waves upon reduction in 0.02 N NH_4Cl at 78% C_2H_5OH, with half-wave potentials at $i_d/2 = -0.27$ and -0.750 V, and at $\log \frac{i}{i_d - i} = 0$, the half wave potential of the second wave is equal to -0.767 V. The first wave is very illegible. As the benzil concentration increases, $E_{1/2}$ increases. The polarographic constant for benzil, $i_d/C = 776$ μA/2. The function $\log \frac{i}{i_d - i}$ relative to E is presented in Fig. 4. The value a is equal to 0.992.

Upon reduction of diacetyl in 0.1 N NH_4Cl at the dropping mercury electrode, two waves appear. The half-wave potential ($E_{1/2}$) of the first is at $i_d/2 = 0.784$ V, and of the second, -1.598 V. The polarographic constant value (i_d/C) for the first wave = 44.7 μA/2, and for the second 30.4 μA/g. The diacetyl polarograms

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* On all polarograms the diffusion current values are quoted at 10 times less than the actual.

Polarographic characteristics for benzoin, benzil, diacetyl and ethylglyoxal

Expt. order no.	Name of substance and phonic electrolyte (20 ml)	Weighed sample (g)	Diffusion current i_d (in μA)	Polarographic constant, i_d/C (in $\mu A/g$)	Half-wave potential ($E_{1/2}$) relative to the saturated calomel electrode (in volts)			Average value for $E_{1/2}$ (in volts)	Average value for i_d/C (in $\mu A/g$)	Electron consumption for one mole of substance, α
					at $i_d/2$	with correction for iR	at $\log\frac{i}{i_d-i}=0$			
1	Benzoin in 0.02 N NH$_4$Cl at 78% C$_2$H$_5$OH	0.0043	–	–	–	–	−1.434	−1.420	735	0.655
2		0.0156	11.5	737	−1.41	−1.393				
3		0.0276	20.2	732	−1.43	−1.400				
4		0.0476	35.0	735	−1.48	−1.427				
1	Benzil in 0.02 N NH$_4$Cl at 78% C$_2$H$_5$OH	0.0090	7.0	777	−0.27 −0.76	−0.749	−0.767	−0.270 −0.758	776	0.992
2		0.0238	18.5	777	−0.27 −0.78	−0.754				
3		0.0362	28.0	774	−0.27 −0.79	−0.748				
1	Diacetyl in 0.1 N NH$_4$Cl	0.0217	–	–	−0.78 −1.58	–	–	−0.781 −1.599	34.2 33.7	–
2		0.0329	–	–	−0.75 −1.58	–				
3		0.0457	–	–	−0.79 −1.62	–				
4		0.0715	2.6 2.8	36 39	−0.76 −0.62	–				
5		0.0877	3.6 2.8	41 32	−0.79 −1.59	–				
6		0.1127	5.4 4.2	47 32	−0.80 −1.60	–				
7		0.1127	6.0 4.2	53 32	−0.80 −1.60	–				
1	Ethylglyoxal in 0.1 N NH$_4$Cl	0.0039	6.7	1723	–	–	−1.750	−1.732	1666	0.40
2		0.0049	7.6	1550	−1.75	−1.739				
3		0.0049	7.6	1550	−1.75	−1.739				
4		0.0060	9.5	1587	−1.72	−1.706				
5		0.0060	9.5	1587	−1.72	−1.706				
6		0.0082	12.6	1536	−1.72	−1.700				
7		0.0082	12.8	1571	−1.72	−1.701				
8		0.0082	12.8	1571	−1.72	−1.701				
9		0.0082	12.6	1536	−1.72	−1.700				
10		0.0082	12.6	1536	−1.72	−1.700				
11		0.0094	20.9	2146	−1.77	−1.735				
12		0.0094	19.6	2085	−1.77	−1.741				

are presented in Fig. 5.

The polarographic results for reduction of ethylglyoxal in 0.1 N NH$_4$Cl are presented in Fig.6. As can be seen from the polarograms, upon reduction of ethylglyoxal in 0.1 N NH$_4$Cl solution, at the dropping mercury electrode, there appears a wave with the half-wave potential at $i_d/2$, equal to −1.715 V; at $\log\frac{i}{i_d-i} = 0$ $E_{1/2}$ equal to −1.75 V. The polarographic constant = 1666 $\mu A/g$. The function $\log\frac{i}{i_d-i}$ relative to E is presented in Fig. 7. The value, α, is equal to 0.4.

EVALUATION OF RESULTS

The polarographic data obtained are presented in the table. A comparison of the benzoin reduction potentials obtained by Semerano [4], by Winkel and Proske [5], and by the authors, has indicated that when the same methods are used for determination, good agreement of results can be obtained, in other words, when using the Semerano method, the benzoin reduction potential = −0.97 V according to our data as compared with Semerano's value of −1.06 V, and when using Winkel and Proske's method, our data give −1.22 V, as compared with Winkel and Proske's −1.22 V. The phonic electrolyte used by Adkins and Cox differ from ours to such a high degree that comparison of our data with that of Adkins and Cox [7] has no meaning.

From a comparison of the benzoin reduction potentials obtained by Tachi [3], Winkel and Proske, and the authors, it follows that the reduction potential for the second wave is equal to −0.60 V, as obtained by the authors, using the same method as that used by Winkel and Proske, which represents good agreement with the results of Winkel and Proske (−0.58 V). The authors, Winkel and Proske, and Tachi are in agreement on the potential value which characterizes the first wave. It should be noted that the first wave is only faintly manifest. The second wave potential of benzil, obtained by the authors and by Winkel and Proske, is close to the reduction potential of Adkins and Cox's first wave. It is true that the phonic electrolyte used by Adkins and Cox is different from that used by the authors and by Winkel and Proske.

It should be noted that upon applying the redox potential method of Winkel and Proske to the data obtained by the authors for diacetyl, the authors have obtained a potential = −0.70 V for the first diacetyl wave, and −1.55 V for the second. The redox potential values obtained agree well with the data of Winkel and Proske (−0.70, −1.58 V).

The benzoin half-wave potential proved to be considerably more positive (−1.420 V) in comparison with the half-wave potential for methylacetylcarbinol (−1.743 V) which indicates a difference due to the effect of the phenyl group as compared with the methyl group upon the reduction of the carbonyl group. The same difference in behavior of phenyl and methyl groups is observed upon comparison of the polarographic data for benzil and for diacetyl − the benzil half-wave potential is considerably more positive (−0.271 and 0.758 V) than the diacetyl half-wave potential (−0.781 and −1.599 V). This again indicates that the proximity of the phenyl group facilitates reduction of the carbonyl group. For the given comparison, certain differences in the phonic electrolyte are disregarded.

Ethylglyoxal reduction proceeds under less favorable conditions (−1.732 V) than that of diacetyl (−0.781, −1.599 V). Consequently the mutual interaction of the adjacent carbonyl groups upon each other favors to a greater extent their reduction at the dropping mercury electrode than does the mutual effect of a ketone and aldehyde grouping.

As seen from the data obtained for the objectives investigated, the presence of a satisfactory proportionality was found between the diffusion current value, i.e., of the wave height versus the concentration of substances. Thus the feasibility of establishing a quantitative analysis for the named objective has been demonstrated.

However, in the case of diacetyl, the small value obtained by the authors for the polarographic constant (34.2 and 33.7 μA/g) points to some sort of variation, for example diacetyl polymerization. The numerical values for the diffusion current are equal for benzoin and benzil per unit mass of substance being reduced (see table). In the case of ethylglyoxal, the polarographic constant has a high value (1666 μA/g).

For the binary mixture of benzoin with benzil, there should be three waves on the polarogram: the first two in the more positive region will attest to the presence of benzil (see table), and the third to the presence of benzoin. From the heights of these waves conclusions as to the concentrations of the substances can be drawn. The same can be said regarding binary mixtures of diacetyl with ethylglyoxal and of diacetyl with methylacetylcarbinol [1]. Thus, for the binary mixtures indicated, it is possible to carry out qualitative and quantitative analyses by the polarographic method.

The discharge of electrons per mole of substance being reduced is expressed in all instances, with the exception of benzil, by a fractional value; consequently, the reduction of these substances at the dropping mercury electrode proceeds irreversibly. The apparent electron consumption for benzil exceeds by approximately two times that for diacetyl.

Thus, the three dicarbonyl compounds examined can be arranged in the following order, according to their ability to be reduced at the dropping mercury electrode:

benzil > diacetyl > ethylglyoxal

which agrees with the structural data for these substances.

SUMMARY

1. The half potentials ($E_{1/2}$), the polarographic constants (i_d/C), the relation of $\log\frac{i}{i_d - i}$ to E, the apparent consumption of electrons upon reduction of one mole of the substance, α, were determined for benzoin, benzil, diacetyl and ethylglyoxal in the concentration range 10^{-3} to 10^{-2} moles / liter in 0.02 N NH_4Cl at 78% C_2H_5OH and in 0.1 N NH_4Cl.

2. On the basis of the proportionality between the height of the wave and the concentration for benzoin, benzil, diacetyl and ethylglyoxal, the feasibility for qualitative and quantitative analysis by polarographic means was determined for the separate components and for their mixture.

3. A comparison of the polarographic data for benzoin and methylacetylcarbinol, and for benzil and diacetyl, was carried out. The easier reduction of the carbonyl group when in proximity to the phenyl group was established.

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• See Consultants Bureau translation page 2151.

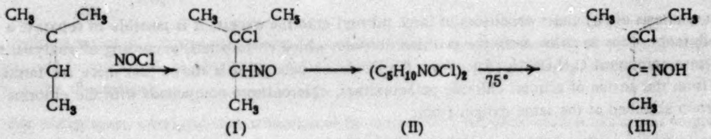
AN INVESTIGATION OF THE INTERACTION PRODUCTS FROM NITROSYL CHLORIDE AND UNSATURATED HYDROCARBONS

I. REACTION WITH TRIMETHYLETHYLENE

S. N. Danilov and K. A. Ogloblin

The products of interaction between unsaturated hydrocarbons and nitrosyl chloride might serve as starting materials for the syntheses of various nitrogen compounds, the possibility of which has been insufficiently utilized up to the present time. From our point of view the most interesting seems to be the utilization of nitrosochlorides for the synthesis of various oximes and amines of compounds which are relatively inaccessible and insufficiently investigated. This determined the content of the present work. As the first objective in the investigation, the nitrosochloride of trimethylethylene has been selected.

The structure and certain transformations of trimethylethylene nitrosochloride were established by the works of Wallach [1] and Schmidt. The latter [2] considers that when nitrosyl chloride is reacted with trimethylethylene*, there is formed at first a monomeric blue liquid nitrosochloride (I), which then transforms into a crystalline product (II), with m.p. 74-75°. The properties and reactions of the latter indicate that this true nitroso compound is the dimer of the initial product of reaction. Dimer (II), upon prolonged heating at its melting point (75°) converts into chloroxime (III), crystals with m.p. 49-50° (from ligroin). The transformations indicated occur according to the scheme



Upon reaction of (III) with sodium methylate, the corresponding methoxy derivative was obtained, and upon boiling with concentrated hydrochloric acid there was obtained the keto alcohol, 2-methylbutanol-2-one-3 [2]**. Schmidt observed only the formation of ammonia [3] upon reduction of (II) and (III) by different methods for the purpose of obtaining the amine.

To achieve our purpose – conversion to oximes and amines – the reactive chloroxime (III) could serve as the starting substance. As has already been indicated, the yield of (II) in the Schmidt experiments consisted of only 15-26%, which did not satisfy us as well as the method for transformation of (II) into (III). The authors have obtained (II) by reaction of nitrosyl chloride with trimethylethylene in ether solution, with a yield of 50%. At the same time were always formed liquid products, blue in color.

The authors have observed that nitrosochloride (II), although stable when allowed to stand in the open air for considerable time, will decompose rapidly when stored in a closed container; the crystals become moist, hydrogen chloride is evolved, the characteristic signs of the chloroxime (III) appear – sharp, piercing odor, and lachrymatory action. The decomposition process terminates with the formation of a hard, yellow, odorless polymer.

The assumption made that the decomposition of (II) is induced by the action of hydrogen chloride, at least in the first stage of chloroxime (III) formation, has been confirmed experimentally. The nitrosochloride (II), after the lapse of a certain time in hydrogen chloride-saturated ether solution, is transformed into the chloroxime (III) in yield of 75-80%. The same process occurs if the reaction products of trimethylethylene with nitrosyl chloride - dimer (II), and the blue liquid are subjected to hydrogen chloride action. The crystals

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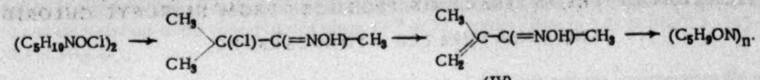
* The nitrosochloride of trimethylethylene was obtained by Schmidt upon reaction of hydrochloric acid with a mixture of trimethylethylene and amyl nitrite, with a yield of 15-26%.

** The author does not indicate the yields of products of dimer gradually disappear, and from the blue solution, upon cooling, can be separated the chloroxime (III) in considerable yield. The processes taking place when the nitrosochloride (II) decomposes upon storage in a closed container, can apparently be represented by the following scheme:

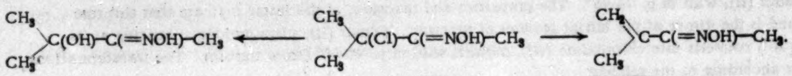


(IV)

The first part of the scheme is experimentally confirmed. The chloroxime apparently then splits off hydrogen chloride and converts into the oxime of methylisopropenylketone (IV) which polymerizes under the conditions indicated to form a hard yellow polymer, similar to the polymer from methylisopropenylketone [4].

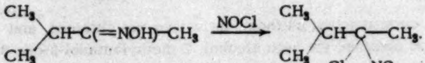
The method for transformation of (II) into (III), derived by the authors, is better than the method proposed by Schmidt, which requires maintenance of strict temperature control (75°), disturbance of which, according to Schmidt himself, and other authors [5], results in complete decomposition of the product; therefore, the Schmidt method is unsuited for obtaining considerable quantities of (III).

It was not possible to separate the individual compounds from the blue liquid products after separation of the crystals of (II), by distillation in vacuo, because at the same time decomposition starts with the formation of dark resin, and the evolution of a large volume of gas. Upon treatment of the blue liquid with calcium carbonate and sodium bicarbonate, in the presence of water, small quantities of dimethylacetylcarbinol oxime (V) and methylisopropylenylketone oxime (IV) were obtained. The two compounds could be formed only in the presence of the reaction products of chloroxime (III):

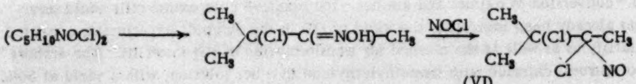


(V) (III) (IV)

Upon synthesis of (II) under conditions of large nitrosyl chloride excess, it is possible to separate a crystalline substance, blue in color, from the reaction mixture, which corresponds, according to analysis, to the dichlornitroso compound $C_5H_9ONCl_2$ (VI). From the literature data [6] it is known that there are formed for example from the action of nitrosyl chloride on ketoximes, chloronitroso compounds with the chlorine and the nitroso group attached at the same carbon atom:



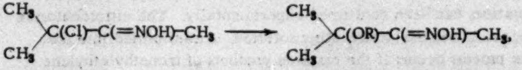
In our case the formation of the blue crystals can be illustrated by the scheme:



(VI)

In addition, from the blue liquid is separated the dichloride $C_5H_{10}Cl_2$.

The chlorine atom in the chloroxime (III) is characterized by great mobility. The authors have found that upon shaking with water for a few minutes the substance transforms completely into the dimethylacetylcarbinol oxime (V). Upon heating a solution of the chloroxime in methyl and ethyl alcohols, in the presence of calcium carbonate or sodium bicarbonate, the corresponding methyl and ethyl esters of dimethylacetylcarbinol are readily formed (VII) and (VIII). Upon reaction with potassium acetate, the corresponding acetic ester (IX) was obtained:



where R = CH_3–(VII), C_2H_5–(VIII), CH_3CO–(IX).

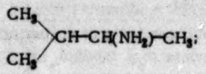
The unsaturated oxime (IV) is easily obtained from the chloroxime (III) on reaction in ether solution with sodium bicarbonate.

It is of interest to note that compound (IV) is derived first in the form of a hard solid, then in a liquid modification form, at which time the liquid modification gradually converts into the solid.

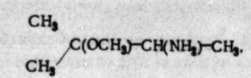
The oxime (IV) is formed likewise from (III), upon reaction with sodium ethylate, but in smaller yield, due to the formation of dimer and trimer.*

The compounds (IV), (V) and (VII) were subjected to catalytic hydrogenation with Raney nickel for the purpose of obtaining the amines and (III) was chemically reduced by means of stannous chloride. In the latter instance only a negligible quantity of 2-methyl-3-aminobutane hydrochloride could be obtained. Catalytic hydrogenation was carried out at room temperature and normal pressure. The saturated amine, 2-methyl-3-aminobutane, was obtained from (IV) with a yield up to 40%, at which time a considerable portion of oxime was split, forming ammonia. For substantiation of the amine structure obtained from (IV), hydrogenation of the saturated methylisopropylketoxime was carried out. The amine (X) obtained in 83% yield was found to be identical with the amine from (IV).

Upon hydrogenation of (VII), 2-methyl-2-methoxy-3-aminobutane (XI) was obtained:

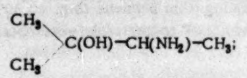


(X)

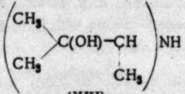


(XI)

Upon hydrogenation of (V), there was obtained with yields up to 70%, the aminoalcohol (XII). Along with it resulted a small quantity of secondary oxamine (XIII):



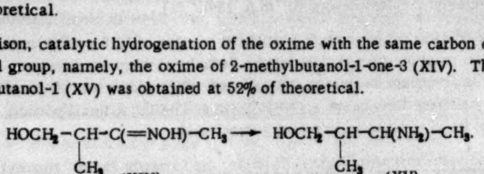
(XII)



(XIII)

Hydrogenation of (V) was carried out in absolute ethanol, in crude alcohol, in crude alcohol containing 10% ammonia, and in methanol, at which time the yields of (XII) in these latter three instances were respectively 51, 47 and 44% of the theoretical.

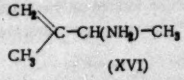
For comparison, catalytic hydrogenation of the oxime with the same carbon chain was carried out, but with the primary alcohol group, namely, the oxime of 2-methylbutanol-1-one-3 (XIV). The corresponding amino alcohol, 2-methyl-3-aminobutanol-1 (XV) was obtained at 52% of theoretical.



$$HOCH_2-\underset{CH_3}{CH}-C(=NOH)-CH_3 \longrightarrow HOCH_2-\underset{CH_3}{CH}-CH(NH_2)-CH_3.$$

(XIV) (XV)

The amino alcohols (XII) and (XV) underwent dehydrattion by means of sulfuric acid, for the purpose of obtaining the unsaturated amine. In both cases the unsaturated amine, 2-methyl-3-aminobutene-1 (XVI) was obtained, at which time its yield from (XII) was considerably greater than from (XV).



(XVI)

The boiling point, density and index of refraction of the amine (XVI) were found to be noticeably higher than the same for amine (X).

EXPERIMENTAL**

Trimethylethylene Synthesis. 200 g of isoamyl alcohol, with b.p. 128-132°, was passed through a porcelain tube containing aluminum sulfate catalyst at 400-415° for 3.5 hours. 101 g of hydrocarbon fraction was obtained with b.p. 20-40° (63.5% of the theoretical yield based on alcohol passed through). Upon fractional distillation over sodium, the fractions obtained were 18.5-23°-15 g (14.8%) 23-37.7°-40.2 g (39.8%); 37.7-38.6°-41 g (40.6%).

---

* Oxime (IV) and its dimer and trimer were obtained by Wallach upon reaction of sodium ethylate with trimethylethylene nitrosate [7].

** A.N. Shirshova assisted in the experimental part.

Nitrosylsulfuric Acid and Nitrosyl Chloride Synthesis. The nitric oxides obtained from the reaction of nitric acid (specific gravity 1.4) with copper shavings were passed, after drying with calcium chloride, through two absorption flasks containing sulfuric acid (specific gravity 1.84). The precipitated crystals of nitrosylsulfuric acid were separated from the mother liquor.

Nitrosyl chloride was obtained by gentle heating of a mixture of finely ground and sifted anhydrous sodium chloride (taken in slight excess) with nitrosylsulfuric acid. The gas, after passing through a calcium chloride tube, was condensed in a flask cooled to minus 45-50°. The yield of nitrosyl chloride was 71-74% of theoretical, based upon nitrosylsulfuric acid.

Trimethylethylene Nitrosochloride (II) Synthesis. Nitrosyl chloride, obtained from 160 g (1.25 moles) of nitrosylsulfuric acid and 90 g of sodium chloride (1.5 moles), was passed into a solution of 51.5 g of trimethylethylene (b.p. 37.5-38.2, n_{α}^{20} 1.3852) in 100 ml of absolute ether, with stirring and salt-ice cooling for 2 hours and 25 min. 48.5 g of crystals, b.p. 70-71.5 (yield 48.7% of theoretical) was separated from the reaction mixture. From their properties the crystals corresponded to trimethylethylene nitrosylchloride [2].

2-Methyl-2-chlorbutanone-3 Oxime (III) Synthesis. a) Nitrosyl chloride (from 100 g of nitrosylsulfuric acid and 60 g of sodium chloride) was passed into a solution of 37 g of trimethylethylene (b.p. 38-39.5, n_{α}^{16} 1.3875) in 50 ml of absolute ether cooled by salt-ice mixture, and stirred, for 3 hours, and for 20-25 minutes hydrogen chloride was passed through. The reaction mixture – blue liquid and colorless crystals (II) – was left at room temperature. After 48 hours the crystals were sucked off from the mother liquor, and on cooling the blue liquid another portion of crystals separated. After 48 hours standing in a sulfuric acid vacuum dessicator the weight of portion I was 14.65 g, m.p. 43-50°; portion II weight was 19.38 g, m.p. 42-49°. After recrystallization from benzene (b.p. 40-60°) three portions of 2-methyl-2-chlorbutanone-3- oxime with m.p. 48-49°, 47-48° and 45-46° respectively were obtained. The substance with m.p. 45-46° was analyzed.

0.1070 g substance: 9.7 ml N_2 (17°, 761 mm). 0.1013 g substance: 9.2 ml N_2 (17°, 764 mm). Found %: N 10.60, 10.66. $C_5H_{10}ONCl$. Calculated %: N: 10.33. 0.0958 g substance; 16.61 g benzene: Δt 0.155°. 0.2498 g substance; 16.61 g benzene: Δt 0.390°. Found: M 192.7, 200.7. $C_5H_{10}ONCl$. Calculated: M 135.5. $(C_5H_{10}ONCl)_2$. Calculated: M 271.0;

Literature data for 2-methyl-2-chlorbutanone-3: m.p. 49-50° [2].

b) Dry hydrogen chloride was passed through a saturated solution of 12.8 g of II (m.p. 70-71.5°) in absolute ether for 1 hour, and the reaction mixture then left for 24 hours at room temperature. On the following day the ether was sucked off in a vacuum dessicator, 9.8 g of hard solid product was obtained with the odor of chloroxime(III). It was recrystallized from benzene (40-60°). M.p. 47-48°. A small portion, remaining undissolved in the benzene, was found to be hydroxylamine hydrochloride.

Interaction of Trimethylethylene with Nitrosyl Chloride, the Latter in Excess. Nitrosyl chloride (from 130 g of nitrosylsulfuric acid and 70 g of sodium chloride) was passed through a solution of trimethylethylene (32.5 g, b.p. 37.2-38.5°, $n_{\alpha}^{19.6}$ 1.3852) in absolute ether (50 ml) for four hours, with stirring and salt-ice cooling. The considerable quantity of flaky crystals on the bottom of the flask was identified as the nitrosochloride (II). The method liquor was brown in color with a greenish tint (excess of NOCl). The reaction mixture was left for 72 hours at room temperature. After 24 hours there were no crystals on the bottom, and the color of the liquid was dark blue. After 48 more hours the crystals which formed on the bottom were separated and dried. The weight, 7 g., m.p. 144-145°. It was identified as hydroxylamine hydrochloride.

There was separated upon distillation of the blue liquid in vacuo: 1) a slightly blue liquid, with b.p. 22-35° at 24 mm, weight 13 g; 2) blue crystals, subliming when distilled in the temperature range 32-40° at 7 mm, weight 2 g. Upon distillation in vacuo of the residue boiling above 69° at 7 mm (dirty-yellow liquid) violent decomposition occurred with the evolution of a large amount of gas (nitric oxide) and effervescence. Everything was converted into a brownish-black resin.

Upon distillation there was separated from the sky-blue liquid a fraction with b.p. 114-117° (772 mm); d_4^{20} 1.0082; n_D^{20} 1.4210; MR_D 35.46. $C_5H_{10}Cl_2$; Calculated 35.02.

Blue Crystals. In color they resembled copper sulfate crystals. The odor was sharp, strongly lachrymatory, highly volatile in air and in vacuo, insoluble in water. Upon prolonged heating with water they disintegrated, the blue color disappearing; the solution was acid in reaction. Easily soluble in ether, in petroleum ether, benzene, carbon tetrachloride, methanol, ethyl acetate, less readily in ethanol. M.p. of the non-crystallized substance 103.5°; blue at melting temperature, yellow-green at 110°.

0.0801 g substance: 5.7 ml N_2 (21°, 779 mm). 0.1124 g substance: 0.1856 g AgCl (Carius)
0.0928 g substance; 16.75 g benzene: Δt 0.160°. 0,1043 g substance; 13.75 g benzene: Δt 0,23°.
Found %: N 8.37; Cl 40.84; M 177.4, 169.1. $C_5H_9ONCl_2$. Calculated %: N 8.23; Cl 41.74; M 170.0.

Thus, the structure 2-methyl-2,3-dichlor-3-nitrosobutane (VI) should be ascribed to the substance.

2-Methylbutanol-2-one-3 oxime (V) Synthesis. 2 g of the chloroxime (III) of m.p. 46-47° was shaken with 20 ml of water at room temperature. All was dissolved after 15 minutes, the solution was neutralized with sodium hydroxide and saturated with sodium chloride. The white flakes which floated up were extracted with ether, and after evaporation of the ether there was obtained 1.05 g of crystals with m.p. 86.5-88.5° and 0.62 g of crystals with m.p. 85-90°. The yield of crude product was 94.2% of the theoretical. After recrystallization from absolute ether the m.p. was 86-87°. A sample mixed with dimethylacetylcarbinol oxime, specially obtained by [8], melted at 86-87°.

2-Methyl-2-methoxybutanone-3 oxime (VII) Synthesis. A mixture of 11.4 g of the chloroxime (III), 80 ml of methyl alcohol and 20 g of calcium carbonate was heated to the boiling point of alcohol for 1 hour, with stirring, and then left for the night. On the following day, after separation of the calcium carbonate, the greater part of the alcohol was distilled off in vacuo under gentle heating, the precipitated crystals sucked off, dried, and weighed. The weight was 9.6 g. Yield of crude product was 87.1% of the theoretical.

After recrystallization from benzene (b.p. 40-60°) there was obtained 6.7 g of substance with m.p. 89-90° and 0.2 g with m.p. 85-86°. The yield for the first portion was 60.8% of the theoretical.

0.1054 g substance: 10.2 ml N_2 (21°, 752 mm). 0.0963 g substance: 9.3 ml N_2 (22°, 759.5 mm).
0.0820 g substance: 16.1 ml CH_4 (13°, 759 mm). Found %: N 11.01, 11.05. Active H atoms 1.08. $C_6H_{13}O_2N$. Calculated %: N 10.68. Active H atoms 1.00. According to literature data [2], m.p. 92°.

2-Methyl-2-ethoxybutanone-3-Oxime (VIII) Synthesis. A mixture of 3 g of the chloroxime (III) with m.p. 47-48°, 7 g of calcium carbonate and 20 ml of redistilled ethanol was heated with stirring for 2 hours and 40 mintues, at a temperature of 70-80°, and then left for the night. On the following day the mineral salts were separated from the transparent liquid, the alcohol distilled off, and the residue twice distilled in vacuo. 1.5 g of colorless liquid of weak odor, with b.p. 84-85° at 8 mm was obtained:

n^{20}_{α} 1.4465.

0.1110 g substance: 9.9 ml N_2 (18°, 771 mm). (Dumas). 0.1144 g substance: 10.25 ml N_2 (23°, 772 mm). Found %: N 10.52, 10.38. $C_7H_{15}O_2N$. Calculated %: 9.65.

Ketoximes with several methyl grups give too high a value for nitrogen by the Dumas method [9].

2-Methyl-2-acetoxybutanone-3 Oxime (IX) Synthesis. A mixture of an ether solution of the chloroxime (III) with anhydrous potassium acetate was stirred at the temperature of boiling ether for 4 hours and 30 min. After separation of the salts from the ether solution, 2/3 of the ether was distilled off, and the residue poured into a beaker. The precipitated crystals were pressed out on a filter paper, m.p. 92-99°. After recrystallization from ligroin – snow-white needles, m.p. 102-103°. The sample mixed with a known sample obtained by another method [8], melted at 101-102°.

2-Methylbutene-1-one-3 Oxime (IV) Synthesis. a) A solution of 16 g of the chloroxime (III), of m.p. 47-49°, in 80 ml of absolute ether, was stirred for 6 hours and 20 minutes at the boiling temperature of ether on reflux with 20 g of sodium bicarbonate. On the following day a yellowish transparent solution was separated from the mineral salts, ther ether distilled off at normal pressure, and the residue distilled in vacuo. 6.5 g of the oxime (IV), with b.p. 65-67° at 11 mm, was obtained, which crystallized in the receivor. M.p. 43-44°. Yield 55.5% of the theoretical

0.1237 g substance: 16.1 ml N_2 (19°, 730 mm). 0.1644 g substance: 21.5 ml N_2 (20.5°, 727.5 mm). 0.0726 g substance; 15.79 g benzene: Δt 0.16°. 0.0648 g substance; 18.80 g benzene: Δt 0.132°. Found %: N 14.29, 14.13; M 148, 135. C_5H_9ON. Calculated %: N 14.14; M 99.

The crystals dissolved readily in benzene, ether, alcohol, ethyl acetate, and poorly in water. After

6 months the crystals over calcium chloride in a dessicator yellowed slightly, but the melting point remained unchanged. From the literature data: [7]: m.p. 44-45°.

b) In a second experiment, using a mixture of sodium bicarbonate and calcium carbonate, there was separated from the reaction products a colorless liquid with the odor of oxime (IV), and b.p. 68° at 8 mm. After 24 hours it was 1/3 crystallized. The m.p. of the crystals was 43-44°, a sample of which when mixed with the oxime of the preceding experiment melted at 43-44°. The liquid separated from the crystals did not crystallize when seeded with an oxime crystal and cooled.

d_4^{19} 0.9529; n_D^{19} 1.4833; MR_D 29.71; calculated 29.02.

0.1376 g substance: 17.4 ml N_2 (21°, 757 mm). 0.1355 g substance: 17.4 ml N_2 (18°, 746.5 mm). Found %: N 14.26, 14.45. C_5H_9ON. Calculated %: N 14.14.

After 24 hours further crystallization of the liquid began in the pycnometer, and after standing 10 days crystallized completely.

Reduction of the Chloroxime (III) with Stannous Chloride. 2.4 g of the chloroxime in 25 ml of absolute ether was added, with snow-salt cooling, to a solution of 15 g of stannous chloride in 50 ml of absolute ether, saturated with hydrogen chloride. On the following day there appeared on the bottom of the flask colorless needle crystals. They were dissolved in water, and through the solution was passed hydrogen sulfide and the precipitated stannous sulfide separated; a small amount of colorless crystals with m.p. 210° was obtained by evaporation of the filtrate in a vacuum dessicator over sulfuric acid. Upon reaction with alkaline solution – an amine odor. M.p. of the HCl salt of the 2-methyl-3-aminobutane was 210°.

Catalytic Hydrogenation of 2-Methylbutene-1-one-3 Oxime (IV)*. a) 6.72 g of the oxime in 100 ml of absolute alcohol was hydrogenated in the presence of Raney nickel. Hydrogenation ceased after absorption of 3170 ml of hydrogen (0°, 760 mm), required for addition, by calculation $2H_2$ 3041 ml, $3H_2$ 4561 ml. After appropriate treatment a fraction was obtained with b.p. 85-85.5° at 764 mm, 0.7 g, n_D^{20} 1.4060. It was a colorless, highly mobile volatile liquid with strong amine odor. Bromine water was instantly decolorized, a solution of potassium permanganate was decolorized within 15-20 minutes.

0.0791 g substance: 11.5 ml N_2 (23°, 764 mm). 0.0873 g substance: 12.6 ml N_2 (23.5°, 760 mm). Found %: N 16.69, 16.41. $C_5H_{13}N$. Calculated %: N 16.07.

The hydrochloride salt was obtained by passing hydrogen chloride into an ether solution of the amine. M.p. 210° (from acetone).

0.0638 g substance: 0.0747 g AgCl. 0.0561 g substance: 0.0656 g AgCl. Found %: Cl 28.97. 28.93. $C_5H_{13}N \cdot HCl$. Calculated %: Cl 28.69.

b) The oxime (IV) was a liquid, b.p. 67.5-71° at 12 mm, $n_D^{18.5}$ 1.483. Weight 3.45 g, 30 ml of absolute alcohol, 2 g of nickel catalyst. 2230 ml of hydrogen (0°, 760 mm) was absorbed, required for addition, according to calculation $3H_2$ 2342 ml. After appropriate treatment the amine fractions were separated (at 761 mm); 1) b.p. 82-84° - 0.2 g, n_D^{23} 1.4047; 2) b.p. 85-86.5° - 1.12 g. The yield for the two fractions was 44% of the theoretical.

For the fraction with b.p. 85-86.5°:

d_4^{23} 0.7478; n_D^{23} 1.4047; MR_D 28.53; calculated 28.71.

0.1015 g substance: 14.6 ml N_2 (21°, 761.5 mm). Found %: N 16.48. $C_5H_{13}N$. Calculated %: N 16.07.

Literature data for 2-methyl-3-aminobutane [10]: b.p. 83-84°, $d^{18.5}$ 1.7574.

2-Methyl-3-aminobutane (X) Synthesis. 7.63 g of 2-methylbutanone-3 oxime (b.p. 155-160°) in 50 ml of absolute alcohol was hydrogenated to the completion of hydrogen absorption. 3056 ml of hydrogen was absorbed, required amount being 3386 ml. After appropriate treatment 7.57 g of the hydrogen chloride salt of 2-methyl-3-aminobutane, or 83.3% yield of theoretical, was obtained. M.p. 208-209° (from acetone). A sample mixed with the amine salt obtained from (IV) melted at 208-209°.

2-Methyl-2-methoxy-3-aminobutane (XI) Synthesis. 2 g of the oxime (VII) with m.p. 89-90° in 90 ml of absolute alcohol. 476 ml of hydrogen was absorbed, 684 ml being required. After appropriate treatment, 0.3 g of amine with b.p. 133-133.5 at 757 mm was obtained. Colorless liquid with amine odor.

0.0914 g substance: 9.6 ml N_2 (20°, 769 mm). Found %: N 12.26. $C_6H_{15}ON$. Calculated %: N 11.96.

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* Hydrogenation in all of the instances described below was carried out under normal conditions in the presence of Raney nickel. The hydrogen volume was corrected to 0° and 760 mm.

2-Methyl-3-aminobutanol-2 (XII) Synthesis. 15 g of the oxime (V) with m.p. 86-88° in absolute ethyl ether solution was hydrogenated to the cessation of hydrogen absorption. 5668 ml of hydrogen was absorbed, 5743 ml ($2H_2$) is required. After separation of catalyst, distillation of the alcohol, and two distillations, the following fractions were obtained (at 764 mm): 1) up to 152° - 0.8 g; 2) 152-156° - 1.0 g; 3) 156-159° - 6.0 g; 4) above 159° - 1.0 g. The yield for the 156-159° fraction was 45.4% of the theoretical.

$d_4^{19.5}$ 0.9256; $n_D^{19.5}$ 1.4497; MR_D 29.92; calculated 30.24.

0.0713 g substance: 8.3 ml N_2 (23°, 765 mm). Found %: N 13.38. $C_5H_{13}ON$. Calculated %: N 13.58.

Literature data [11]: b.p. 157-158° (743 mm), d_{15}^{15} 0.9291.

Below is given a summary of 2-methyl-3-aminobutanol-2 yield upon hydrogenation of the oxime (V) in various experiments.

Order No.	Solvent	Oxime taken (g)	Fractions obtained		Yield for 154-180° frac. (%)	Note
			154-180° (g)	180-212° (g)		
1	Absolute ethanol	20	12.25	2.72	70	
2	The same	18.1	12.03	1.87	75.4	Spontaneously crystallized
3	Crude ethanol	5.24	2.74	1.0	50.9	
4	10% NH_3 solution in crude alcohol	10	4.1	2.3	46.6	
5	Methanol	5	1.95	1.0	44.3	

From the above-boiling fractions obtained in the experimental series, a substance with b.p. 75-76.5° at 7 mm was separated, corresponding to the secondary oxamine (XIII). Literature data for (XIII): b.p. 252-254 at 757 mm [12]. M.p. about 30°.

0. 1281 g substance: 8.3 ml N_2 (20°, 778 mm). Found %: N 7.67. $(C_5H_{11}O)_2NH$. Calculated %: N 7.40.

2-Methyl-3-aminobutanol-1 (XV) Synthesis. 2-Methylbutanol-1-one-3 was obtained by condensation of methylethylketone with formaldehyde.* The oxime (XIV) was obtained from it by the usual procedure, in 77% yield of theoretical – a viscous liquid with b.p. 134-135° at 15 mm, which rapidly crystallized, m p. 42-44°

0.1029 g substance: 10.8 ml N_2 (23°, 764 mm). Found %: N 12.03. $C_5H_{11}O_2N$. Calculated %: N 11.96.

Literature data for (XIV) [15]: b.p. 144° at 20 mm.

20 g of crystalline oxime (XIV) was hydrogenated in 105 ml of absolute alcohol solution to the cessation of hydrogen absorption. 7609 ml of hydrogen was absorbed, 7658 ml being required. The catalyst was separated and the alcohol distilled off. Upon distillation the following fractions were obtained (at 770 mm): 1) b.p. 191-192° - 3.2 g, n_D^{20} 1.4570; 2)b.p. 192-194°–6,0 g, n_D^{20} 1.4576. Yield for the two fractions was 52.3%. Upon subsequent distillation the fraction with b.p. 194° at 770 mm was separated. Viscous, colorless liquid with an ammoniacal odor.

d_4^{20} 0.9389; n_D^{20} 1.4576; MR_D 29.94; calculated 30.24.

0.0868 g substance: 10.2 ml N_2 (22°, 771 mm). Found %: N 13.66. $C_5H_{13}ON$. Calculated %: N 13.58.

2-Methyl-3-aminobutene-1 (XVI) Synthesis. a) 2-Methyl-3-aminobutanol-2 (XII) Dehydration. A solution of 6 g of sulfuric acid (specific gravity 1.84) in 10 ml of water was poured into 6.1 g of the amino alcohol in 10 ml of water solution cooled with ice. The mixture was distilled at 30 mm on a Wood's alloy bath for 4 hours and 10 minutes. The Wood's alloy temperature at the start was 90°, and at the end 143°. In the flask – a viscous dark liquid with greenish tint. Left for the night. The following day a solution of 20 g of sodium hydroxide in 30 ml of water was poured into the flask, and the amine was distilled off. The distillate stood over KOH granules for 2 hours, the upper layer was then separated and distilled over KOH. The fractions obtained (at 770 mm) were: 1) 85-88° - 0.67 g, n_D^{20} 1.4267; 2) 88-89° 1.7 g. The yield for the two fractions was 47% of theory.

Fraction 2 – a colorless, volatile, highly mobile liquid with a very sharp ammoniacal odor.

d_4^{20} 0.7785; n_D^{20} 1.4274; MR_D 28.09; calculated 28.24.

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* See [13], and also [14].

0.0911 g substance: 12.8 ml N_2 (21°, 772.6 mm). 0.1312 g substance: 18.7 ml N_2 (21°, 768.3 mm). Found %: N 16.44, 16.59. $C_5H_{11}N$. Calculated %: N 16.45.

Hydrogen Chloride Salt was obtained by passing dry hydrogen chloride into an ether solution of the amine. The salt was highly hygroscopic. It was purified by precipitation from alcohol solution by absolute ether. M.p. 153-153.5°. After a second precipitation m.p. was 153-153.5°.

Picrate. - long, thin, scaly needles, yellow in color. M.p. 171-172° (from dilute alcohol). The amine (XVI) was obtained in 54.3% yield in the second experiment. For the fraction with b.p. 87.5-89.5 at 750 mm was found:

d_4^{20} 0.7784; n_D^{20} 1.4265; MR_D 28.06; calculated 28.24; $d_4^{23.4}$ 0.7752; $n_\alpha^{23.4}$ 1.4210; MR_α 27.85; calculated 28.07.

b) Dehydration of 2-Methyl-3-aminobutanol-1 (XV). Under the same conditions as was described in the preceding experiment, there was obtained upon dehydration of 6.5 g of (XV), a fraction with b.p. 89-94° in the amount of 0.8 g. Due to the small amount of substance, it could not be purified further.

d_4^{20} 0.8132; $n_D^{18.5}$ 1.4305; n_D^{20} 1.4260.

SUMMARY

1. The conditions were determined for carrying out the reaction between trimethylethylene and nitrosyl chloride in order to obtain either the nitrosochloride (II) or the chloroxime (III). It was demonstrated that transformation of (II) into (III) occurs easily under the action of hydrogen chloride in ether solution. 2-Methyl-2,3-dichlor-3-nitrosobutane (VI), not described in the literature, was separated from the reaction products during the synthesis of II, using excess nitrosyl chloride.

2. A procedure was found for obtaining hydroxy-, methoxy-, ethoxy- and acetoxy-substituted derivatives of 2-methylbutanone-3-oxime from the chloroxime (III), and similarly of methylisopropenylketone oxime.

3. The catalytic hydrogenation on Raney nickel of: methylisopropenylketone, methylisopropylketone, methylhydroxyisopropylketone, methylmethoxyisopropylketone and β-methyl-γ-keto-butanol oxime was carried out. The corresponding amines were obtained, among them 2-methyl-2-methoxy-3-aminobutane and 2-methyl-3-amintobutanol-1 not mentioned in the literature.

4. Upon dehydration of 2-methyl-3-aminobutanol-2 and 2-methyl-3-amino-butanol-1 there was obtained the unsaturated 2-methyl-3-aminobutene-1 amine, not mentioned in the literature.

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AN INVESTIGATION OF THE INTERACTION PRODUCTS FROM NITROSYL CHLORIDE AND UNSATURATED HYDROCARBONS

II. REACTION WITH ISOBUTYLENE

K. A. Ogloblin

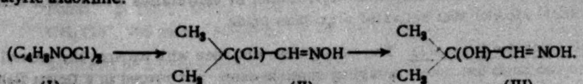
As is known, isobutylene gives with nitrosyl chloride a crystalline product (I), to which is ascribed the structure of the dimerized oxime of α-chlorisobutyric aldehyde, although there is no proof of such a structure in the literature. Upon heating of (I) with hydrochloric acid, it was not possible to separate any individual compound, and, among the reaction products it was only possible to prove qualitatively the presence of the aldehyde group [1,2].

To the author it was of interest also to examine compound (I) while continuing an investigation of the interaction products of nitrosyl chloride with unsaturated hydrocarbons.

In the preceding article [3] the authors demonstrated that the chlorine atom in 2-chloro-2-methylbutanone-3 oxime has great mobility and transforms easily to a hydroxyl or alkoxyl group, which is apparently explained by its position at the tertiary carbon atom, and by the presence in the α,β-position of the double bond between carbon and nitrogen. It can be assumed that chlorine, likewise, will possess similar properties in α-chlorisobutyric aldoxime.

If, however, product (I) appears to be the oxime of α-chlorisobutyric aldehyde dimer, then under the appropriate conditions there might be obtained from it the α-substituted oxime of isobutyric aldehyde. In addition to being useful for the synthesis of various nitrogen compounds from isobutylene, the transformations indicated could serve as sufficiently convincing proof of both the structure for (I) and of α-chlorisobutyric aldoxime in the dimer form.

The oxime of 2-chloro-2-methylbutanone-3, obtained from the chloronitro compound of trimethylene by simply shaking with water for a few minutes, transforms completely into the oxime of 2-methylbutanol-2-one-3 ketoalcohol [3]. Considering the fact that (I) seems to be the dimer of α-chlorisobutyric aldoxime, it could be expected that the substitution reaction of chlorine for hydroxyl will not proceed easily. In fact, the indicated transformation proceeds only upon heating, at which time the first stage of the reaction is apparently the transformation of dimer (I) into the monomer (II), which then enters into reaction with water to form α-hydroxyisobutyric aldoxime:

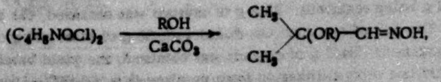


$$(C_4H_8NOCl)_2 \longrightarrow (CH_3)_2C(Cl){-}CH{=}NOH \longrightarrow (CH_3)_2C(OH){-}CH{=}NOH.$$

(I) (II) (III)

The reaction was carried out in the presence of finely-ground calcium carbonate, and completion of reaction was determined by cessation of carbon dioxide evolution.

By substituting various alcohols for water, there can be obtained the corresponding α-alkoxyderivatives of isobutyric aldoxime. In this way the author has obtained the methoxy-, ethoxy- and n-propoxy-derivatives.*



$$(C_4H_8NOCl)_2 \xrightarrow[CaCO_3]{ROH} (CH_3)_2C(OR){-}CH{=}NOH,$$

where R = CH_3—(IV), C_2H_5—(V), n-C_3H_7—(VI).

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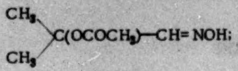
* Recently a patent [4] was published for the derivation of alkoxyisobutyraldoximes (IV), (V) and (VI) by an analogous method. The author had the opportunity of becoming acquainted with it only in the autumn of 1951, when his work had already been completed.

Compounds (III) and (IV) represent viscous liquids (IV) and (V) — crystalline bodies.

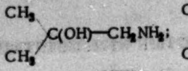
Upon reaction of (I) with potassium acetate in glacial acetic acid solution, the acetoxyderivative (VII) was obtained.

Products (III), (IV) and (V) were hydrogenated on Raney nickel to the corresponding amines (VIII), (IX) and (X):



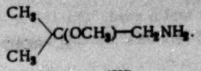
$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(OCOCH_3)-CH=NOH;$

(VII)



$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(OH)-CH_2NH_2;$

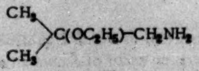
(VIII)



$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(OCH_3)-CH_2NH_2.$

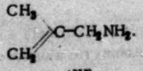
(IX)

Through dehydration of (VIII) with the aid of sulfuric acid, the unsaturated amine (XI) was obtained:



$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(OC_2H_5)-CH_2NH_2$

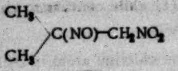
(X)



$\genfrac{}{}{0pt}{}{CH_3}{CH_2}\!\!>C-CH_2NH_2.$

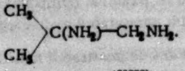
(XI)

The nitrosonitrocompound (XII) which was formed as a by-product upon synthesis of (I) was likewise hydrogenated to the diamine (XIII):



$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(NO)-CH_2NO_2$

(XII)



$\genfrac{}{}{0pt}{}{CH_3}{CH_3}\!\!>C(NH_2)-CH_2NH_2.$

(XIII)

As a rule compounds (III) through (VII) are obtained with yields 50-60% of the theoretical.

Having in mind the ease of preparation of the nitrosochloride of isobutylene (yields up to 70%), we assume that the above-indicated reactions may be of interest from the preparative viewpoint.

EXPERIMENTAL

(With the participation of A. N. Shirshova)

Synthesis of Nitrosylsulfuric Acid and Nitrosyl Chloride. The nitrosylsulfuric acid, obtained from nitrogen oxides and sulfuric acid as has been described in the preceding article, was placed in a wide-necked flask with part of the mother liquor, into which flask was introduced a tube ending with glass filter No. 1. Dry air was sucked through the homogeneous liquid mass of nitrosylsulfuric acid for a few hours, while heating on a water bath, to remove oxides of nitrogen. After cooling of the solution, the precipitated nitrosylsulfuric acid crystals were separated from the mother liquor and used to obtain the nitrosyl chloride, as has been shown earlier [3].

Isobutylene Synthesis. Isobutylene was obtained from trimethylcarbinol by dehydration with sulfuric acid [5], and mainly by dehydration of isobutyl alcohol over activated aluminum oxide.

Synthesis of α-Chlorisobutyric Aldoxime Dimer (I). The isobutylene, and then with stirring, the nitrosyl chloride, were introduced at −15° into two large test tubes containing absolute ether, and placed in a Dewar flask with cooling mixture. Within a few minutes after introduction of the nitrosyl chloride the formation of small crystals in the tubes became noticeable, and after 2 hours the reaction mixture from the precipitated crystals solidified. The temperature within the test tubes did not go above minus 12°. Everything was left overnight. 16 hours later the temperature in the test tubes was minus 10°. The crystals were filtered off by vacuum from the blue liquid, and washed with cooled ether until the sky-blue tint disappeared. After removal of the ether residue in a vacuum dessicator — shiny white crystals, with m.p. 98-99°. The first test tube was filled with 72 g of ether, 25 g of isobutylene, 35 g of nitrosyl chloride (29.2 g being required). 39.2 g of crystals was obtained, the yield based upon isobutylene was 72.3% of theoretical. The second test tube was filled with 68 g of ether, 30 g of isobutylene, 31 g of nitrosyl chloride (35 g being required). 34.7 g of crystals was obtained, the yield based upon nitrosyl chloride was 60.3% of the theoretical. After one recrystallization from gasoline (b.p. 60-80°) — long needles, m.p. 103-104°.

Upon distillation of the blue liquid in vacuo, the fraction with b.p. 68-70° at 19 mm was separated — the dark blue liquid presently solidifying into a mass of colorless crystals with m.p. 80-82°. After recrystallization from benzene the m.p. was 82-83°.

0.1281 g substance: 23.7 ml N_2 (19°, 752 mm). Found %: N 21.24. $C_4H_8O_3N_2$. Calculated %: N 21.21.

The crystals with m.p. 82-83° corresponded to 1-nitro-2-nitroso-2-methylpropane (XII) [6], according to analysis and properties. The substance (1.5 g) was hydrogenated in an alcoholic solution of Raney nickel. In 4 hours 923 ml of hydrogen was absorbed, 1374 ml of hydrogen (at 22° and 775 mm) being required. After removal of the catalyst, the alcoholic solution was acidified with hydrochloric acid, the alcohol evaporated, and the salt residue recrystallized from alcohol. 0.15 g of chlorohydrate (XII) crystals, with m.p. 292-295°, was obtained. According to the literature data [7], m.p. is 303°.

0.0628 g substance: 9.9 ml N_2 (25°, 752 mm). Found %: N 17.67. $C_4H_{12}N_2 \cdot 2HCl$. Calculated %: N 17.36.

Synthesis of α-Hydroxyisobutyric Aldoxime (III). A flask equipped with thermometer, stirrer and reflux condenser, the upper end of which was connected to a trap for CO_2 (50% KOH solution) was filled with 180 ml of water, 30 g of finely pulverized and sifted calcium carbonate and 15 g of (I) with m.p. 102.5-103°. The crystals of (I), when the flask was heated, transformed into greenish curd-drops, and at a liquid temperature of about 80°, reaction with the calcium carbonate with CO_2 evolution began continuing without further heating, and with the evolution of heat. When the curds had disappeared and the CO_2 had ceased to evolve, the yellow liquid was heated to boiling. The whole experiment lasted not more than one hour. 2.69 g of carbon dioxide was evolved, 2.71 g being the theoretical. The solution was separated from the calcium carbonate precipitate and was treated with ether on a reflux for 25-30 hours. From the ether extract, after distilling off the ether and then distilling the residue, a fraction with b.p. 95-97.5° at 10 mm was obtained with a weight of 8.13 g. The yield was 64% of the theoretical. The colorless viscous liquid dissolved readily in water, alcohol, ether, poorly in benzene.

For the α-hydroxyisobutyric aldoxime fraction with b.p. 83-83.5° at 3 mm, which was obtained in one of the experiments, there was found:

d_{20}^{20} 1.0675; d_4^{20} 1.0655; n_D^{20} 1.4625; MR_D 26.63; Calculated 26.40.

0.1458 g substance: 16.7 ml N_2 (17°, 758.2 mm). Found %: N 13.38. $C_4H_9O_2N$. Calculated %: N 13.57.

The literature data for the α-hydroxyisobutyric aldoxime [8]: b.p. 110° at 19 mm.

Synthesis of α-Methoxyisobutyric Aldoxime (IV). 10 g of (I), 20 g of finely-ground calcium carbonate in 40 ml of methanol was stirred for one hour while heating to boiling. Completion of reaction was determined by cessation of carbon dioxide evolution. 1.7 g of CO_2 was evolved, 1.78 g should have been evolved. After removal of the calcium carbonate, and distilling off of the alcohol, the residue was treated with ether to separate (IV) from the calcium chloride, the ether was distilled off, and the residue redistilled in vacuo. 6 g (63% of the theoretical) of the substance with b.p. 83-85° at 15 mm was obtained, which crystallized in the condenser. M.p. 39-40°. After recrystallization from petroleum ether with freezing, needle-like crystals with m.p. 43-44° were obtained. They dissolved readily in water and in the usual organic solvents. Molecular weight determination pointed to association of the compound.

0.2639 g substance: 16.27 g benzene: Δt 0.435°. 0.2287 g substance: 16.05 g benzene: Δt 0.395°. Found: M 193.2, 187.0. 0.0834 g substance: 18.4 ml CH_4 (17°, 766 mm). 0.0723 g substance: 15.6 ml CH_4 (18°, 766 mm). Found %: active H 0.93, 0.90. $C_5H_{11}O_2N$. Calculated %: active H 0.95; M 117.1.

Synthesis of α-Ethoxyisobutyric Aldoxime (V). By a procedure analogous to that described in the preceding experiment the ethoxy derivative with b.p. 64-65.5° at 4 mm was obtained. The odor was peculiar, though not unpleasant. The substance was soluble in water and in the usual organic solvents; upon filling a pycnometer, it crystallized into long, dagger-like crystals. The crystals were pressed out on filter paper. M.p. 38-40°.

d_4^{40} 0.9464; n_D^{40} 1.4323; MR_D 35.97; calculated 35.75.

0.1240 g substance: 0.2220 g AgI (Zeitzel). Found %: OC_2H_5 34.36. $C_6H_{13}O_2N$. Calculated %: OC_2H_5 34.35.

Synthesis of α-n-Propoxyisobutyric Aldoxime (VI). 24.3 g of (I) 82 g of n-propyl alcohol and 40 g of calcium carbonate were taken. Experimental conditions were the same as in the preceding two cases. Reaction started at 70° and spontaneously continued with heat evolution (up to 85°). After 2 hours of heating to boiling, followed by the usual treatment, and three distillations, fractions at 83-85° and at 85-86°, at 8 mm, were separated, with weights of 2.39 and 9.05 g respectively. The yield for the two fractions was 39.5%. The fraction with b.p. 85-86 at 8 mm was a colorless, viscous liquid, with a faint odor resembling the methoxy- and ethoxy-derivatives.

d_{20}^{20} 0.9436; d_4^{20} 0.9420; n_D^{20} 1.4414; MR_D 40.70; Calculated 40.37.

0.1342 g substance: 11.6 ml N_2 (18°, 749 mm). 0.1206 g substance: 10.1 ml N_2 (17°, 748 mm). Found %: N 9.85, 9.55. $C_7H_{15}O_2N$. Calculated %: N 9.64.

Synthesis of *a*-Acetoxyisobutyric Aldoxime (VII). 60 g (0.49 mole) of isobutylene nitrosochloride was dissolved with gentle heating in 250 ml of glacial acetic acid. To the green solution was added 50 g (0.51 mole) of anhydrous potassium acetate in 200 ml of glacial acetic acid solution. The mixture was stirred while heating at a temperature of 60°, the heating then discontinued, while the temperature rose spontaneously to 73°. Potassium chloride precipitated in large amount. The reaction mass was stirred for an additional hour while heating to 80-85°. On the following day the yellow transparent liquid was separated from the potassium chloride precipitate, washed with acetic acid, and the dried precipitate weighed 33.65 g – 0.45 mole. The acetic acid was distilled off in vacuo from the reaction products at 35° and 16 mm.

Upon distillation of the residue a fraction with b.p. 89-92° at 3 mm was obtained, weighing 37.9 g (yield 53% of theoretical). Repeated distillation of this fraction gave a fraction with b.p. 91-92° at 6 mm. Viscous, colorless liquid almost without odor. Soluble in water, alcohol, ether, benzene, acetic acid, carbon tetrachloride; insoluble in gasoline.

d_4^{20} 1.0757; n_D^{20} 1.4503; MR_D 36.28; Calculated 35.76.

0.2768 g substance: 23.3 ml N_2 (21°, 750 mm). Found %: N 9.56. $C_6H_{11}O_3N$. Calculated %: N 9.65.

Synthesis of 1-Amino-2-methoxy-2-methylpropane (IX). 6.4 g of (IV) in 70 ml of distilled alcohol solution was hydrogenated with Raney nickel under the usual conditions. 2.174 ml of hydrogen was absorbed, 2.448 ml being required. After separation of the nickel the solution was neutralized with hydrochloric acid. 5.2 g of the amine hydrochloride, with m.p. 112-113°, was obtained by the usual procedure, and purified by repeated precipitation by ether from the alcohol solution. Yield 68.2%.

0.1069 g substance: 0.1118 g AgCl. Found %: Cl 25.87. $C_5H_{13}ON \cdot HCl$. Calculated %: Cl 25.42.

The free base (IX) was separated from the salt by the action of 12% caustic potash solution with subsequent distillation. The distillate was saturated with solid caustic potash, the amine layer separated, and extracted with ether. After drying with caustic potash, the ether was removed and upon redistillation the amine (IX) fraction with b.p. 121.5-122.5° at 753 mm was obtained. It was a colorless, transparent liquid with ammoniacal odor. It was soluble in water and the usual organic solvents.

d_4^{20} 0.8677; n_D^{20} 1.4210; MR_D 30.14; Calculated %: 30.35.

0.1662 g substance: 19.4 ml N_2 (19°, 747 mm). Found %: N 13.32. $C_5H_{13}ON$. Calculated %: N 13.56.

Synthesis of 1-Amino-2-ethoxy-2-methylpropane (X). 27.25 g of (V) in 230 ml of absolute alcohol was hydrogenated with Raney nickel in a rotating steel autoclave at a pressure of 110 atmospheres and a temperature of 18°. After distillation through a fractionating column with 10 theoretical plates, the following amine fractions were obtained (at 755 mm): 1) 131-132 1.3 g, n_D^{20} 1.4182; 2) 132-133° 14.3 g. The yield for the 132-133° fraction was 59%. Colorless, transparent liquid with amine odor. Soluble in water and the usual organic solvents.

d_4^{20} 0.8497; n_D^{20} 1.4189; MR_D 34.82; Calculated 34.97.

0.1479 g substance: 16.2 ml N_2 (19°, 739.5 mm). 0.1414 g substance: 15.1 ml N_2 (20°, 743 mm). Found %: N 12.35, 12.05. $C_6H_{15}ON$. Calculated %: N 11.95.

Synthesis of 1-Amino-2-methylpropanol-2 (VIII). 34 g of the oxime (III) in 200 ml of alcohol solution was hydrogenated in the presence of Raney nickel in a rotating steel autoclave at the pressure of 80 atmospheres and 100° temperature. From the hydrogenation products 15.5 g of 1-amino-2-methylpropanol-2 was separated with a b.p. of 149-150° at 755mm. Yield was 53% of the theoretical. In separate experiments the yield of amino-alcohol was higher than 60%. For the fraction with b.p. 149-150° at 755 mm:

d_4^{18} 0.9323; n_D^{18} 1.4460; MR_D 25.50; Calculated 25.62.

For the fraction with b.p. 150-150.5° at 762 mm, obtained in a separate experiment:

d_{20}^{20} 0.9294; d_4^{20} 0.9278; n_D^{20} 1.4452; MR_D 25.58; Calculated 25.62.

0.0869 g substance: 12.1 ml N_2 (22°, 752 mm). 0.1133 g substance: 15.8 ml N_2 (20.5°, 749 mm). Found %: N 15.62, 15.68. $C_4H_{11}ON$. Calculated %: N 15.71.

Literature data [9] b.p. 150.5-151.5° at 762 mm, d_0^0 0.9500, d_0^{14} 0.9389.

Synthesis of 1-Amino-2-methylpropene-2 (XI). 15.1 g of distillate of ammoniacal odor was obtained from 23.3 g of the aminoalcohol by dehydration with sulfuric acid under the conditions indicated in the literature [10], from which 8.75 g of substance was isolated after drying and distilling, boiling mainly at 83-84°. Upon subsequent distillation, two fractions of the amine were obtained (at 763 mm): 1) 72-82° 2.03 g and 2) 82-85° 5.59 g.

From the 72-82° fraction the hydrochloride salt was obtained. After two precipitations with ether, the b.p. was 179.5-180.5°.

Picrate – long, narrow, flat flakes (up to 2 centimeters in length) with m.p. 201-201.5° (from absolute alcohol).

The fraction with b.p. 82-85° at 763 mm was a colorless transparent liquid with a specific (but not ammoniacal) odor. Insoluble in water. Upon heating with alkali a strong ammonia odor appeared; the same also occurred after several days of storage.

Hydrogen Chloride Salt, purified by reprecipitation from alcohol solution by ether, had a m.p. of 185.5-186.5°.

0.0796 g substance: 0.1042 g AgCl. 0.0846 g substance: 0.1114 g AgCl. Found %: Cl 32.39, 32.58. $C_4H_9N \cdot HCl$. Calculated %: Cl 32.96.

Picrate – m.p. 201.5-202° (not recrystallized).

0.1002 g substance: 16 ml N_2 (18°, 768 mm). Found %: N 18.63. $C_6H_2(NO_2)_3OH \cdot C_4H_9N$. Calculated %: N 18.66.

The unsaturated amine (XI) content in the fraction 82-85° was determined by titration (using bromophenol blue).

0.1088 g substance: 11.1 ml 0.1 N H_2SO_4. 0.0932 g substance: 9.5 ml 0.1 N H_2SO_4. Found %: amine 72.6, 72.5.

The yield of amine (XI) upon dehydration was about 33%.

The fraction with b.p. 82-85° was twice redistilled, and each time was dried over NaOH beforehand.

Fractions obtained (at 759 mm): 1) 73.5-77° 0.2 g, n_D^{20} 1.4282; 2) 77-79° 1.42 g.

The 77-79° fraction at 759 mm was a colorless, highly mobile, liquid with a strong ammoniacal odor: d_{20}^{20} 0.7838; d_4^{20} 0.7827; n_D^{20} 1.4300;* MR_D 23.47. $C_4H_9N|^{=}$. Calculated 23.63.

Literature data [10]: b.p. 76-77.7° at 746 mm, n_D^{20} 1.4312.

SUMMARY

1. The oximes of α-hydroxyisobutyric aldehyde, α-methoxyisobutyric aldehyde, α-ethoxyisobutyric aldehyde, α-n-propoxyisobutyric aldehyde and α-acetoxyisobutyric aldehyde were obtained from the chloronitrosocompound of isobutylene upon reaction with water and with alcohols.

2. 1-Amino-2-methylpropanol-2, its methyl and ethyl esters, and 1,2-diamino-2-methylpropane were obtained upon hydrogenation of the oximes of α-hydroxyisobutyric aldehyde, α-methoxyisobutyric aldehyde, α-ethoxyisobutyric aldehyde, and 1-nitro-2-nitroso-2-methylpropane, respectively.

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* It is of interest to note that after 2-3 minutes the refractive index was already 1.4293, which indicated a ready change of the amine in air. ** See Consultants Bureau translation page 607 . *** See Consultants Bureau translation page 2167.

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ACYL PEROXIDES. DICAPRYL PEROXIDE

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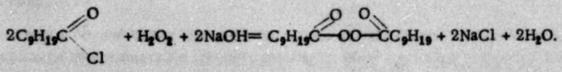
Acyl peroxide compounds are of interest from many points of view. On the basis of the reaction discovered by N. A. Prilezhaev, acyl hydroperoxides have been employed for determination of structure and for the quantitative analysis of unsaturated compounds [1,2,3]. Lately the diacyl peroxides have found application in organic synthesis as alkylating agents, or to produce many other interesting transformations [4].

At the same time the number of acyl peroxide compounds which have been isolated and determined up to the present time is relatively small, and it should be noted here that many of them have not been isolated in sufficiently pure form.

Among the acyl hydroperoxides (of per acids) have been described: performic, peracetic, perpropionic, perbutyric, percaproic, perbenzoic, and a series of others (in this number are also derivatives of the dicarboxylic acids – of succinic, glutaric, phthalic, camphoric, oxalic and terephthalic – possessing one hydroperoxide group), obtained chiefly by reaction of hydrogen peroxide (concentrated or dilute) with the appropriate acids, anhydrides or chloroanhydrides of the acids (see [5] and others) in the presence of small quantities of sulfuric acid or alkali,

Of the diacyl peroxides there are known the peroxides of diacetyl, dichloroacetyl, dipropionyl, dibutyryl, diisovaleryl, dicapryl, dinitrobenzoyl, acetylbenzoyl and some others, obtained principally by interaction of the anhydrides or the chloroanhydrides of the corresponding acids with hydrogen peroxide (in the presence of alkaline reagents with the alkali or alkaline earth salts (see [6]) and others).

The authors carried out acylation of hydrogen peroxide by capric acid chloroanhydride. With selected ratio – 2 moles of chloroanhydride per 1 mole of hydrogen peroxide – the dicapronyl peroxide results according to the reaction:



$$2C_9H_{19}C\begin{matrix}\nearrow O\\ \searrow Cl\end{matrix} + H_2O_2 + 2NaOH = C_9H_{19}\overset{O}{\overset{\|}{C}}-OO-\overset{O}{\overset{\|}{C}}C_9H_{19} + 2NaCl + 2H_2O.$$

The dicapryl peroxide (or didecanoyl according to the Geneva nomenclature) is in the form of a crystalline substance with m.p. +41°. It has relatively small oxidizing properties: iodine separates very slowly from acidified potassium iodide solution. Dicapryl peroxide is soluble in organic solvents (ethyl ether, alcohols, ketones, hydrocarbons) but is insoluble in water.

EXPERIMENTAL

10.2 g of capric acid chloroanhydride (obtained from pure capric acid with a m.p. of 31.4, according to the method of Kraft and Koenig [7] was added dropwise, while stirring rapidly, to a mixture of 35 ml of 3% aqueous hydrogen peroxide and 44 ml of 5% sodium hydroxide solution at room temperature. The mixture was allowed to stand for 24 hours. Colorless crystals of the peroxide (displaying a laminar structure under the microscope) precipitated after this lapse of time, were filtered off, and washed with water. Yield was 5.6 g or 61.3% of the theoretical.

After triple recrystallizations from ethanol, the peroxide melted at +41°. It gave qualitative reactions for active oxygen – iodine separated from potassium iodide solution, upon heating thiocyanate solution was slowly colored, but it did not react with lead tetra-acetate, the indicator for the absence of hydroperoxide group.

Elementary analysis results for the dicapryl peroxide (carried out according to the semimicro method of Pregl):

0.0322 g substance: 0.0823 g CO_2; 0.0332 g H_2O. 0.0408 g substance: 0.1050 g CO_2, 0.0427 g H_2O. Found %: C 69.75, 70.20; H 11.27, 11.72. $C_{20}H_{38}O_4$. Calculated %: C 70.17; H 11.20.

0.2235 g substance: 22.04 g benzene: Δt 0.150°. Found: M 346.0. $C_{20}H_{38}O_4$. Calculated: M 342.5.

The active oxygen content was determined by the iodometric method in glacial acetic acid solution: titration after 24 hours [8]:

0.0456 g substance: 2.65 ml 0.1 N $Na_2S_2O_3$. 0.0468 g substance: 2.7 ml 0,1 N $Na_2S_2O_3$. Found %: active O 4.65, 4.61. $C_{20}H_{38}O_4$. Calculated %: active O 4.67.

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ADDITION OF PHOSPHONACETIC ESTER AND ITS HOMOLOGS TO UNSATURATED ELECTROPHILIC REAGENTS

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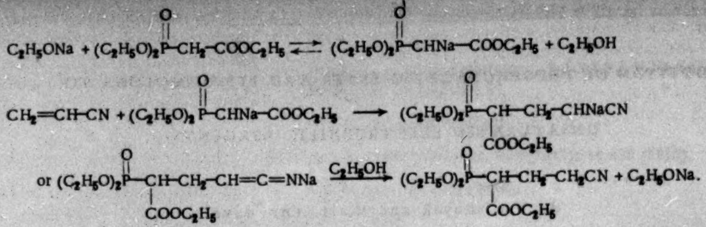
A. E. Arbuzov and Dunin [1] synthesized for the first time in 1914 the ethyl ester of phosphonacetic acid by reaction of the ethyl ester of bromoacetic acid with the full ethyl ester of phosphorous acid. In an analogous manner certain representatives of the phosphonocarboxylic acid series were likewise synthesized by them: the ethyl esters of phosphonoformic, α- and β-phosphonopropionic and phosphonobutyric acids. In 1924 Nylen [2] synthesized the phosphonoacetic ester by reaction of chloroacetic ester with sodium diethylphosphite in ether solution. A. E. Arbuzov and Kamai [3] later improved this method considerably, and demonstrated that substitution of ether by ethanol brought the yield of phosphonoacetic ester up to 95% of the theoretical. In 1929 A. E. Arbuzov and Razumov [4] synthesized the homolog of phosphonoacetic ester – the ethyl ester of α-diethylphosphonopropionic acid in 45% yield by the reaction of methyl iodide on the sodium derivative of phosphonoacetic ester. It was established at the same time that there is formed considerable quantity of the monosodium salt of α-phosphonopropionic acid ester and of ethyl iodide along with the normal reaction product. Such an abnormal reaction course was explained on the grounds that the sodium derivative of the phosphonoacetic ester may exist in two tautomeric forms. With the potassium phosphonoacetic ester the reaction proceeds only according to the normal scheme: the phosphonopropionic ester yield reaches 85%. A. E. Arbuzov and Razumov [5] further demonstrated the tautomerism of phosphonoacetic ester in the case of the methyl iodide reaction with the sodium derivative of the ethyl ester of diisobutylphosphonoacetic ester. Lately Chavene [6], employing the method described in the work of Arbuzov and Razumov, synthesized α-diethylphosphono-n-hexylacetic ester.

From a review of the literature data cited it can be seen already that phosphonoacetic ester appears to be a substance of considerable interest, presenting great theoretical interest for the study of the tautomerism phenomenon and for the purpose of synthesis of organophosphorous compounds.

As has already been indicated, it was established through the investigations of A. E. Arbuzov and Razumov that there are mobile hydrogen atoms in phosphonoacetic ester, which are replaceable by the alkali metals in a manner corresponding to acetoacetic, malonic and cyanacetic esters. It seemed probable to us that phosphonoacetic ester can display an analogy with the indicated esters in other reactions also: addition reactions, reactions with aldehydes and ketones, and so forth, which are likewise connected with the mobility of the hydrogen atoms of the methylene group. Having in mind the considerable interest of similar reactions, completely uninvestigated up to the present time, the authors have undertaken in the present work a study of the addition reactions of phosphonacetic ester to certain unsaturated electrophilic reagents: the nitrole of acrylic acid, the methyl esters of acrylic, methacrylic and maleic acids, the ethyl ester of cinnamic acid, the unsaturated ketones of benzal-, furfural-acetone and mesityl oxide.

In a majority of the cases, reactions were carried out according to the procedure described by one of us for the addition reactions of dialkyl phosphorous acids to unsaturated compounds [7]. Preliminary experiments carried out by the authors have shown that phosphonacetic ester, in the presence of sodium ethylate, adds to the majority of unsaturated compounds used for this purpose, with more or less ease. The addition of phosphonacetic ester to acrylic acid nitrile in the presence of a small quantity of sodium ethylate proceeds vigorously, accompanied by a heat of reaction evolution with partial resinification of the reaction mixture. Attempts to distill fractionally result in complete resinification. Satisfactory results were obtained by conducting the reaction in ethanol solution. The products from the addition of the phosphonacetic ester to one or two molecules of acrylonitrile were isolated with a general yield of 50% of theory.



$$C_2H_5ONa + (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-CH_2-COOC_2H_5 \rightleftarrows (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-CHNa-COOC_2H_5 + C_2H_5OH$$

$$CH_2{=}CH-CN + (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-CHNa-COOC_2H_5 \longrightarrow (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-\underset{\substack{|\\ COOC_2H_5}}{CH}-CH_2-CHNaCN$$

$$\text{or } (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-\underset{\substack{|\\ COOC_2H_5}}{CH}-CH_2-CH{=}C{=}NNa \xrightarrow{C_2H_5OH} (C_2H_5O)_2\overset{O}{\overset{\|}{P}}-\underset{\substack{|\\ COOC_2H_5}}{CH}-CH_2-CH_2CN + C_2H_5ONa.$$

Reaction between the phosphonacetic ester and methyl acrylate in the presence of sodium ethylate also proceeds quite vigorously with large heat evolution from the reaction mixture. The yield of addition product—the methyl ethyl ester of α-diethylphosphonglutaric acid—was 41%. Similarly, for the course of reaction between methyl methacrylate and the ethyl ester of cinnamic acid, there were obtained: the methylethyl ester of α-methyl-α'-diethylphosphonglutaric acid in 45% yield, and the diethyl ester of α-diethylphosphon-β-phenylglutaric acid. To carry out the latter reaction, which under normal conditions proceeded only very slowly, the reaction mixture was heated several hours on a water bath. The esters obtained were in the form of colorless, very viscous liquids, surface-active with respect to water.

Phosphonacetic ester addition to the methyl ester of maleic acid proceeded with the same difficulty. Regardless of the prolonged heating of the reaction mixture, the addition product—the dimethyl ester of α-diethylphosphon-α,β,γ-propanetricarboxylic acid—was obtained only in 12% yield.

The addition of phosphonacetic ester to benzalacetone in the presence of sodium ethylate proceeds easily; under more rigorous conditions the addition of furfuralacetone proceeds. The addition of phosphonacetic ester to mesityl oxide failed to go even when the reaction mixture was heated to 250°. Apparently, in the last instance, the effect of spatial hindrance and the electrophilic decrease of the carbon atom of the unsaturated ketone due to the presence of the two attached methyl groups, is evident.

It was of further interest to the authors to study the addition of phosphonacetic ester homologs to certain unsaturated compounds. For this purpose n-butylphosphonacetic ester was synthesized and its addition to acrylic acid nitrile, methylacrylate and methylmethacrylate was carried out. In contrast to phosphonacetic ester, the n-butylphosphonacetic ester adds quite smoothly to acrylonitrile in the absence of solvents, with moderate heat evolution. The addition product—the ethyl ester of α-(β-cyanethyl)-α-diethylphosphoncapric acid was obtained in 84% yield. Similar results were likewise obtained with the methylphosphonacetic acid ester. Addition products of n-butylphosphonacetic ester to methylacrylate and to methylmethacrylate were obtained in high yields (of the order 80-85%). All products synthesized were in the form of thick, colorless liquids, surface-active with respect to water.

EXPERIMENTAL

Addition of Phosphonacetic Ester to Acrylic Acid Nitrile. 7.5 g of phosphonacetic ester and 3.45 g of acrylic acid nitrile were dissolved in 20 ml of absolute ethanol. The flask with the reaction mixture was connected to a reflux condenser, and then a saturated sodium ethylate solution in ethanol slowly added dropwise. During the course of reaction the flask was cooled with running water, since reaction was accompanied by considerable heat evolution, resulting in boiling of the alcohol if not cooled sufficiently. After completion of reaction, the alcohol was distilled off and the residue fractionally distilled in vacuo. Separated were:

1) a small amount of original phosphonacetic ester;

2) 2.5 g of the ethyl ester of diethylphosphon-(α-cyanethyl)-acetic acid with b.p. 185-186° (4 mm); n_D^{20} 1.4470; d_4^{20} 1.1065;

0.1860 g substance: 32.98 ml NaOH (T 0.0225). Found %: P 11.05. $C_{11}H_{20}O_5NP$. Calculated %: P 11.17;

3) 3 g of diethylphosphon-di-(β-cyanethyl)-acetic acid ethyl ester with b.p. 230-231° (5 mm); n_D^{20} 1.4580; d_4^{20} 1.1307;

0.2070 g substance: 32.85 ml NaOH (T 0.02477). Found %: P 8.64. $C_{14}H_{23}O_5N_2P$. Calculated %: P 9.04.

Addition of the Phosphonacetic Ester to the Methyl Ester of Acrylic Acid. A saturated sodium ethylate solution was slowly added dropwise to a mixture of 10.4 g of phosphophonacetic ester and 4 g of methylacrylate. The reaction was accompanied by considerable heat evolution. In all, 10 drops of ethylate were added. After standing for a short time the reaction mixture was fractionally distilled. After distilling off the unreacted phosphonacetic ester, 5.85 g of the mixed methylethyl ester of α-diethylphosphonglutaric acid with b.p. 209° (4 mm) was obtained: n_D^{20} 1.4510; d_4^{20} 1.1474;

0.1320 g substance: 21.38 ml NaOH (T 0.0225). Found %: P 10.08. $C_{12}H_{23}O_7P$. Calculated %: P 10.00.

Addition of Phosphonacetic Ester to the Methyl Ester of Methacrylic Acid. The reaction was carried out by heating 13.2 g of phosphonacetic ester with 6.7 g of methylmethacrylate in the presence of sodium ethylate on a water bath; dropwise addition of the ethylate was likewise carried out while heating. The color of the reaction mixture by the end of the heating period had changed from pink to dark-red. As the result of a double distillation of the reaction mixture, 7.69 g of the methylethyl ester of α-methyl-*d*-diethylphosphonglutaric acid was isolated, b.p. 199-201° (13 mm); n_D^{20} 1.4450; d_4^{20} 1.1172;

0.1269 g substance: 20.1 ml NaOH (T 0.0225). Found %: P 9.86. $C_{13}H_{25}O_7P$. Calculated %: P 9.57.

Addition of Phosphonacetic Ester to Ethyl Cinnamate. Sodium ethylate solution was added dropwise to a mixture of 5 g of freshly distilled ethyl cinnamate and 7 g of phosphonacetic ester. Heat evolution was not observed. The reaction mixture was heated for 5 hours on a boiling water bath after the addition of about 1 ml of the ethylate solution. As the result of distillation in vacuo, 3 g of α-diethylphosphon-β-phenylglutaric acid diethyl ester was isolated with b.p. 190-192° (2 mm); n_D^{20} 1.4740; d_4^{20} 1.1272;

0.1967 g substance: 25.06 ml NaOH (T 0.0225). Found %: P 7.93. $C_{19}H_{30}O_7P$. Calculated %: P 7.76.

Addition of Phosphonacetic Ester to the Dimethyl Ester of Maleic Acid. To a mixture of 8.2 g of phosphonacetic ester and 5.9 g of the methyl ester of maleic acid there was added about 2 ml of saturated sodium ethylate solution. There was no evolution of heat. After 2 hours of heating, the reaction mixture was distilled in vacuo on a water bath. 1.7 g of α-diethylphosphon-α-β-γ-propanetricarboxylic acid dimethyl ester was obtained with b.p. 173-175° (3 mm); n_D^{20} 1.4395; d_4^{20} 1.1730.

0.2376 g substance: 34.0 ml NaOH (T 0.0225). Found %: P 8.91. $C_{14}H_{25}O_7P$. Calculated %: P 8.42.

Addition of Phosphonacetic Ester to Benzalacetone. Sodium ethylate solution was added dropwise to a mixture of 6.6 g of benzalacetone and 10 g of phosphonacetic ester. Strong heat evolution was observed. After heating for a short time on the water bath, the reaction mixture was distilled in vacuo. 8 g of α-diethylphosphono-β-phenyl-γ-acetobutyric acid ethyl ester was obtained with b.p. 207-210° (6 mm); n_D^{20} 1.5019; d_4^{20} 1.1356.

0.1203 g substance: 16.46 ml NaOH (T 0.0225). Found %: P 8.52. $C_{18}H_{27}O_6P$. Calculated %: P 8.4.

Addition of Phosphonacetic Ester to Furfuralacetone. The addition reaction failed to go at room temperature and when heated on a water bath. 10 g of phosphonacetic ester, 5 g of furfuralacetone and 3 ml of saturated sodium ethylate solution were heated in a sealed tube at 130-135° for 10 hours. The color of the solution changed from light-yellow to dark-brown. As a result of fractional distillation of the reaction mixture, the initial furfuralacetone, and phosphonacetic ester were recovered and 1.5 g of the addition product — the ethyl ester of α-diethylphosphon-β-furil-γ-acetobutyric acid with b.p. 138-139° (3 mm); n_D^{20} 1.4490; d_4^{20} 1.109.

Found %: P 8.50. $C_{16}H_{25}O_7P$. Calculated %: P 8.61.

The product obtained was a brown-colored liquid; the vapors were bright yellow in color. Upon standing it gradually resinified.

Synthesis of n-Butylphosphonacetic Ester. 150 ml of absolute ether and 3.4 g of finely cut sodium were placed in a three-necked round-bottomed flask, equipped with reflux condenser, stirrer and dropping funnel. Then 35 g of phosphonic ester was added dropwise with stirring. The reaction mixture was stirred for 1.5 hours almost to the complete disappearance of the sodium. The small amount of sodium which did not enter into reaction was removed from the reaction mixture with the aid of a long glass needle. 24 g of n-butyl bromide was then gradually added to the reaction mixture, and the mixture was then heated on a water bath for 2.5 hours. The colloidal sodium bromide precipitated when the reaction mixture was boiled for a short time with activated carbon. After filtering off the precipitate, and distilling off the ether, the residue was fractionally distilled from an Arbuzov flask. 21.2 g of n-butyl phosphonacetic ester was obtained with b.p. 154-156° (9 mm); n_D^{20} 1.4360; d_4^{20} 1.0406.

0.1628 g substance: 28.69 ml NaOH (T 0.0225). Found %: P 10.98. $C_{12}H_{25}O_5P$. Calculated %: P 11.07.

Addition of n-Butylphosphonacetic Ester to Acrylic Acid Nitrile. 4 drops of saturated sodium ethylate solution in ethanol was gradually added, with ice cooling, to a mixture of 6 g of n-butylphosphonacetic ester and 1.5 g of acrylic acid nitrile. The reaction proceeded with considerable heat evolution from the mixture. There was no resinification. After a half-hour standing at room temperature the reaction mixture was distilled in vacuo. 5 g of α-(β-cyanethyl-)-α-diethylphosphonocaproic acid ethyl ester was obtained with b.p. 186-187° (2 mm); n_D^{20} 1.4500; d_4^{20} 1.0641.

0.1492 g substance: 22.46 ml NaOH (T 0.0225). Found %: P 9.36. $C_{15}H_{28}O_5NP$. Calculated %: P 9.33.

Addition of Methylphosphonacetic Ester to Acrylic Acid Nitrile. From 5 g of methylphosphonacetic ester [b.p. 126° (5 mm)] and 3 g of acrylic acid nitrile, under conditions similar to those described in the preceding experiment, there was obtained 3.6 g of the ethyl ester of diethylphosphon-(β-cyanethyl-)-acetic acid, with b.p. 176-178° (5 mm); n_D^{20} 1.4430; d_4^{20} 1.0960.

0.2283 g substance: 36.84 ml NaOH (T 0.0225). Found %: P 10.06. $C_{12}H_{22}O_5NP$. Calculated %: P 10.65.

Addition of n-Butylphosphonacetic Ester to the Methyl Esters of Acrylic and of Methacrylic Acids. Experiment I. The reaction was carried out with 7 g of n-butylphosphonacetic ester and 2 g of the methyl ester of acrylic acid. Considerable heat evolution was observed. 7.2 g of the methyl ethyl ester of α-n-butyl-α-diethylphosphonglutaric acid with b.p. 179-181° (3 mm) was obtained; n_D^{20} 1.4510; d_4^{20} 1.1002.

0.1164 g substance: 16.3 ml NaOH (T 0.0225). Found %: P 8.72. $C_{16}H_{31}O_7P$. Calculated %: P 8.47.

Experiment II. As the result of reaction between 4 g of n-butylphosphonacetic ester and 1.5 g of methylmethacrylate, there was obtained 4.2 g of the methylethyl ester of α-methyl-α'-n-butyl-α'-diethylphosphonoglutaric acid with b.p. 169-170° (2 mm); n_D^{20} 1.4490; d_4^{20} 1.0818.

0.1945 g substance: 23.89 ml NaOH (T 0.0225). Found %: P 7.65. $C_{17}H_{33}O_7P$. Calculated %: P 8.01.

SUMMARY

1. It was demonstrated that phosphonacetic ester and its homologs are capable of addition to unsaturated electrophilic reagents in the presence of sodium ethylate: to unsaturated nitriles, ester of acids and to ketones.

2. Addition products of phosphonacetic ester to acrylic acid nitrile, methylacrylate, methylmethacrylate, cinnamic acid ethyl ester, maleic acid methyl ester, benzal- and furfural-acetone, and similarly addition products of n-butylphosphonacetic ester to acrylonitrile, methylacrylate and methylmethacrylate were obtained and characterized.

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ADDITION OF HYDROGEN BROMIDE TO DIALLYL

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N. Ya. Demyanov [1] was the first to study the addition of HBr to diallyl, who, by passing gaseous hydrogen bromide into cooled diallyl to the point of saturation, obtained the crystalline dibromide – 2,5-dibromhexane, and also an addition product which he did not further examine. Later Grishkevich-Trokhimovsky [2] demonstrated that the liquid product from the addition of HBr to diallyl represents a mixture of dibromhexanes, in which 1,5-dibromhexane predominates, and so HBr addition to diallyl occurs simultaneously according to Markownikoff's rule and in contradiction to the rule at the same time.

The stepwise addition of gaseous hydrogen bromide to diallyl and separation of incomplete addition to one double bond was studied. Upon reaction of diallyl with concentrated hydrochloric acid [3], hydrogen bromide dissolved in glacial acetic acid [10], and with gaseous hydrogen bromide [11], the products of incomplete addition were isolated earlier, and represented 5-chlor-, 5-brom- and 5-iod-hexene-1. On the basis of the preceding investigation, it could be expected that upon addition of gaseous hydrogen bromide to diallyl, the first step of the reaction would result either in the secondary bromide – 5-bromhexene-1 (I), or along with it the primary – 6-bromhexene-1 (II); the latter could occur in this instance if the first stage of HBr addition to the diallyl proceeded in both directions.

(I) $CH_2{=}CH{-}CH_2{-}CH_2{-}CHBr{-}CH_3$; (II) $CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_2Br$.

The experiments described below indicate that the product of incomplete addition of hydrogen bromide to diallyl results in good yield (about 60% of the theoretical) if gaseous hydrogen bromide is passed into the diallyl, with mechanical stirring, in an amount equal to half of that required for saturation of one double bond. The product obtained in this manner boils over a wide range (137.5-151°), and can be separated into two fractions with b.p. 137.5-138.5° and 150-151° by fractional distillation. Comparing the physical properties of these fractions among themselves, and also with the properties of other unsaturated bromides with the double bond at the end of the chain which are described in the literature, it can be concluded that the fraction with b.p. 150-151° possessing the higher boiling point and higher specific gravity, should represent the primary bromide – 6-bromohexene-1, and the fraction with b.p. 137.5-138.5 – the secondary bromide – 5-bromhexene-1 (see table).

Substance	Boiling point	d_4^{20}	n_D^{20}
$CH_2{=}CH{-}CH_2Br$ [5]	70–71°	1.3980	1.46545
$CH_2{=}CH{-}CH_2{-}CH_2Br$ [4]	98.5-99	1.3230	1.46215
$CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2Br$ [4]	126	1.2581	1.46397
$CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_2Br$	151	1.2169	1.4672
$CH_2{=}CH{-}CHBr{-}CH_3$ [6]	7° (10 mm)	1.2998 (25°)	1.4618
$CH_2{=}CH{-}CH_2{-}CH_2{-}CHBr{-}CH_3$	138	1.1997	1.4625

To confirm that the fraction with b.p. 137.5-138.5° in reality does represent 5-bromohexene-1, this bromide was synthesized by another method which is common for the synthesis of unsaturated bromides, namely – the reaction of phosphorous tribromide, in the presence of pyridine, with hexene-1-ol-5 [4]. Upon comparing their physical constants, both products were found to be identical. The primary character of the bromide with b.p. 150-151° was first of all demonstrated by the fact that when it was reacted with $AgNO_2$, according to V. Meyer, it behaved like a primary halogen derivative forming in the end an orange-red salt solution of nitrolic acid. Furthermore, upon reacting this bromide with sodium acetate in glacial acetic acid, it transformed into the acetate, which, upon saponification, formed an alcohol which differed from its isomeric secondary alcohol, hexene-1-ol-5, by higher constants, and represented hexene-1-ol-6.

Substance	Boiling point	d_4^{20}	n_D^{20}
$CH_2{=}CH{-}CH_2{-}CH_2{-}CHOH{-}CH_3$	139°	0.8390	1.4325
$CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_2OH$	155.5-156	0.8453	1.4364

Moreover, upon reacting the above-boiling bromide with alkali in water-alcohol, it transformed into the previously known ethyl ether of hexene-1-ol-6 $CH_2{=}CH{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}O{-}C_2H_5$ [7]. All of these characteristics point to the conclusion that the bromide of b.p. 150-151° represents 6-bromohexene-1.

Thus, in the first step, the addition reaction of hydrogen bromide to diallyl proceeds in two possible directions. The second step of the reaction was studied by the example of hydrogen bromide addition to the secondary bromide. It was found at this time that upon reaction of hydrogen bromide with 5-bromohexene-1, under the same conditions, that the addition proceeded almost entirely according to Markownikoff's principle, and a mixture of liquid and crystalline 2,5-dibromohexanes resulted.

EXPERIMENTAL

Diallyl, obtained by reacting metallic sodium with allyl iodide [8] and having the following properties: b.p. 56-59°; d_4^{20} 0.6897; n_D^{20} 1.4018, served as the starting substance for the work.

Addition of HBr to Diallyl. 164 g (2 moles) of diallyl was placed in a flask equipped with an inlet tube reaching almost to the bottom of the flask, a reflux condenser and a mechanical stirrer. The flask was cooled in a mixture of ice and salt, and 81 g (1 mole) of hydrogen bromide, obtained from bromine, red phosphorus and water, was introduced, with vigorous agitation. The flask was then removed from the cooling mixture and left overnight. On the following day the flask contents were distilled through a Vigreux column, at which time the following resulted on the average:

1) diallyl with b.p. 56-60° – 81 g; 2) fraction with b.p. 130-160° – 129 g; 3) residue – 32.5 g.

The recovered diallyl was again saturated with HBr (1 mole of HBr for 2 moles of diallyl); thus 240 g of diallyl was treated and 309 g of fraction with b.p. 130-160° and 130 g of residue, representing a mixture of dibromohexanes, were obtained. The 130-160° fraction was separated into the following fractions as the result of multiple distillation through a Vigreux column 0.6 meter in height:

I) b.p. 137.5-138.5° at 712 mm – 12.5 g; II) b.p. 138.5-150° – 56 g; III) b.p. 150-151° – 101 g. Total yield was 59% of the theoretical; the 137.5-138.5° fraction had a 26% yield; fraction 150-151° – 21.4%. Fraction I constants: b.p. 138° at 712 mm; d_4^{20} 1.1997; n_D^{20} 1.4625; MR_D 37.39 calculated 37.21.

0.2834 g substance: 0.4583 g CO_2; 0.1678 g H_2O. 0.2168 g substance: 0.2503 g AgBr (Carius). Found %: C 44.10; H 6.58; Br 49.12. $C_6H_{11}Br$. Calculated %: C 44.17; H 6.75; Br 49.08.

Fraction II constants: b.p. 151 at 712 mm; d_4^{20} 1.2169; n_D^{20} 1.4672; MR_D 37.18; calculated 37.21.

0.3060 g substance: 0.4941 g CO_2; 0.1815 g H_2O. 0.2826 g substance: 0.3263 g AgBr (Carius). Found %: C 44.03; H 6.59; Br 49.18. $C_6H_{11}Br$. Calculated %: C 44.17; H 6.75; Br 49.08.

Reaction of PBr_3 with Hexene-1-ol-5. 35 g (0.13 mole) of phosphorous tribromide was placed in a Wurtz flask equipped with dropping funnel and condenser, and then with constant shaking a mixture of 30 g (0.3 mole) of hexene-1-ol-5 (see above constants), obtained from reduction of allylacetone by metallic sodium in water-ether medium, and 6.3 g (0.08 mole) of pyridine was added, dropwise. After addition of all of the mixture, the reaction mixture was distilled. From three experiments 116 g of crude product was obtained, which was washed with a weak alkaline solution, then with water, dried with anhydrous calcium chloride and then distilled through a fractionating column. As the result of distillation there were obtained: I) a fraction with b.p. 60-65° – 11 g; II) a fraction with b.p. 137-140° – 77 g; the above boiling residue was 20 g.

Upon repeated distillation, the 60-65° fraction boiled at 56-60°, and represented diallyl. Thus, along with replacement of the hydroxyl group by bromine, in the given instance there occurred a partial splitting out of HBr from the resulting bromide which, probably, again added to the diallyl forming a mixture of secondary and primary bromides (the residue boiling as above). For this reason, therefore, the 137-140° fraction was again redistilled, for the purpose of purification, through a good fractionating column, at which time 67 g of the substance of b.p. 137-138° at 708 mm was obtained. The yield was 45.6% of the theoretical.

d_4^{20} 1.2005; n_D^{20} 1.4636; MR_D 37.44; calculated 37.21. 0.3020 g substance: 0.4887 g CO_2; 0.1848 g H_2O. 0.2544 g substance: 0.2934 g AgBr (Carius). Found %: C 44.13; H 6.80; Br 49.07. $C_6H_{11}Br$. Calculated %: C 44.17; H 6.75; Br 49.08.

Water-Alcohol-Alkali Reaction with the 150-151° b.p. Fraction. 32 g of the 150-151 b.p. fraction was added to 17 g of KOH solution in 100 ml of 95% alcohol, and the mixture was heated to boiling on a bath for 3 hours. At the same time potassium bromide separated. After termination of the heating, water was added, the upper layer of reaction product was separated, the water layer extracted with ether, the ether extractions combined with the main bulk of product was washed with water, dried with potash, and the ether distilled off, and the residue redistilled (almost completely in the 141-143° range). Since the boiling point of the substance was too low for the proposed alcohol, and corresponded more closely to the ethylhexenyl ether,

$CH_2=CH-CH_2-CH_2-CH_2-CH_2-O-C_2H_5$ [7], the liquid was boiled over metallic sodium for further purification, and was redistilled, at which time it boiled almost entirely at 139-139.5 (713 mm). The yield was 17.5 g (68.3%).

d_4^{20} 0.7877; n_D^{20} 1.4144; MR_D 40.64; calculated 40.32. d_4^{15} 0.7947; n_D^{15} 1.4178.

0.1856 g substance: 0.5097 g CO_2; 0.2110 g H_2O. Found %: C 74.90; H 12.63. $C_8H_{16}O$.
Calculated %: C 75.00; H 12.50.

Hexene-1-yl-6-acetate. 48 g of 6-bromohexene-1 was added to a hot solution of 50 g of anhydrous sodium acetate in 120 ml of glacial acetic acid. The mixture was heated to boiling on an oil bath for 18 hours, followed, after cooling, by dilution with water, separation of the upper layer, extraction of the liquid with ether, combination of the ether layer with the reaction product, washing with soda solution, then with water, dried with anhydrous calcium chloride, the ether distilled off, and the residue distilled through a fractionating column. Practically all of the substance boiled in the 166-170° range. The yield was 28.1 g, or 66% of the theoretical.

B.p. 169-170° at 704 mm; d_4^{20} 0.8992; n_D^{20} 1.4241; MR_D 40.30; calculated 40.33.

0.2075 g substance: 0.5134 g CO_2; 0.1860 g H_2O. Found %: C 67.48; H 9.96. $C_8H_{14}O_2$.
Calculated %: C 67.61; H 9.86.

Hexene-1-ol-6. 23.5 g of hexene-1-ol-6 acetic ester was heated to boiling on a bath with 15 g of KOH solution in 30 ml of alcohol for 3 hours, the mixture then diluted with water, extracted with ether, the ether extraction washed with water, dried with anhydrous potash, and the ether distilled off.

The residue, after removal of the ether, had a b.p. of 153-156.° The yield was 14.1 g (85.4%). B.p. 155.5-156° at 718 mm; d_4^{20} 0.8453; n_D^{20} 1.4364; MR_D 30.95; calculated 30.97.

0.2832 g substance: 0.7465 g CO_2; 0.3087 g H_2O. Found %: C 71.89; H 12.11. $C_6H_{12}O$.
Calculated %: C 72.00; H 12.00.

HBr Addition to 5-Bromohexene-1. Hydrogen bromide was passed into 104 g (0.63 mole) of 5-bromohexene-1 to an excess weight of 58 g (0.69 mole), with ice-salt cooling, and everything was then left overnight at room temperature. On the following day the reaction product was poured into water, washed twice with water, and then dried with anhydrous calcium chloride. Many crystals precipitated from the liquid upon standing at room temperature, the quantity of which was considerably increased upon standing in cooling mixture. The crystals removed from the liquid portion by suction filtration weighed 79 g (51% yield). After recrystallization from ether (by slow evaporation of the solvent) the substance melted at 38-39° and represented meso-2,5-dibromohexane [1]. The liquid portion of the reaction product was distilled in vacuo, at which time it almost completely boiled at 72-74° (4 mm). Yield was 57 g (36.7%). There remained in the distilling flask only a negligible residue (1.5 g) boiling as above, d_4^{20} 1.5769; n_D^{20} 1.5018; MR_D 45.64; calculated 45.44 [97].

The yield of dibromides mixture was 136 g, or 87.8% of the theoretical

SUMMARY

1. 5-Bromohexene-1 and 6-bromohexene-1 were obtained by addition of hydrogen bromide to diallyl.

2. 5-Bromohexene-1 was likewise obtained from the reaction of PBr_3 with hexene-1-ol-5 in the presence of pyridine.

3. Hexene-1-yl-6-acetate and hexene-1-ol-6 were obtained from the reaction of sodium acetate in glacial acetic acid with 6-bromohexene-1 and with saponfication.

4. Upon reaction of HBr with 5-bromohexene-1 the addition proceeds according to Markownikoff's rule, and a mixture of stereoisomeric 2,5-dibromohexanes results.

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SULFONATION OF UNSATURATED COMPOUNDS

I. SULFONATION OF ACROLEIN AND OF CROTONIC ALDEHYDE

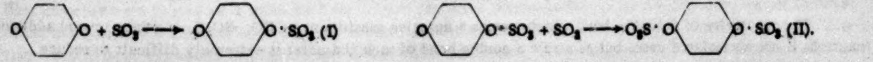
A. V. Dombrovsky

As far as is known, sulfonation of unsaturated aldehydes has not been achieved up to the present time, nor have their sulfo derivatives been obtained. The direct reaction of sulfonating agents on acrolein and on crotonic aldehyde leads to instant polymerization and resinification. A.P. Terentyev [1] has worked out for the first time a procedure for the introduction of the sulfo group into molecules of acidophobic compounds. A.P. Terentyev with his co-workers synthesized sulfo acids and their furane pyrrole and unsaturated hydrocarbon derivatives with one, or two double bonds [2], using as the sulfonating agent complex-bound sulfuric anhydride with pyridine, so-called pyridine-sulfotrioxide.

The author attempted to use pyridine-sulfotrioxide for sulfonation of acrolein and of crotonic aldehyde. It was found that the heating of these aldehydes with pyridine-sulfotrioxide in sealed tubes at 80-100° led to extensive polymerization; but at room temperature the reaction proceeded so slowly that it was not possible to separate any considerable amounts of sulfonation products. Therefore, pyridine-sulfotrioxide was found to be an unsuitable sulfonating agent for these aldehydes.

Experimentation has indicated that a suitable and sufficiently convenient sulfonating agent for unsaturated aldehydes is found to be dioxane-sulfotrioxide – a complex compound between dioxane and sulfuric anhydride (I).

In 1906 A. E. Favorsky [3] investigated and obtained for the first time complex compounds of dioxane with bromine, iodine, sulfuric acid and others. Similarly in 1938 Suter and his co-workers [4] obtained dioxane-sulfotrioxide (I) and dioxane-disulfotrioxide (II) from the reaction of dioxane with a solution of sulfuric anhydride in dichlorethane:


(I) (II).

As the authors indicated, the sulfonating action of complex (I) differs but little from the action of complex (II). Dioxane-sulfotrioxide proved to be a more potent sulfonating agent than pyridine-sulfotrioxide. It sulfonates many unsaturated compounds reasonably well at -10° and 0°, but is considerably less stable than pyridine-sulfotrioxide, and requires immediate use after its preparation. However, it can be preserved in a refrigerator for several days without noticeable decomposition. Isobutylene [5] and styrene [6] were sulfonated by the use of dioxane-sulfotrioxide. In the first instance there were isolated the sulfo acids:

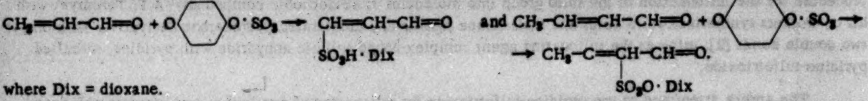
$$HO_3S-CH_2-\overset{CH_3}{\overset{|}{C}}=CH_2 \text{ and } HO_3S-CH_2-\overset{CH_3}{\overset{|}{C}}=CH-SO_3H,$$

and styrene gave ω-styrene-sulfonic acid $C_6H_5-CH=CH-SO_3H$.

Dioxane-sulfotrioxide reacts vigorously in the cold (at 0°) with acrolein and with crotonic aldehyde. The reaction was carried out by gradual addition of an equivalent quantity of dioxane-sulfotrioxide to the unsaturated aldehyde in dioxane solution. The temperature of the reaction mixture was maintained at about 0° for the whole time. By controlling the extent of the sulfonation, monosulfonated acids of the corresponding aldehydes result. The reaction proceeds very rapidly. Completion of sulfonation is easily determined by cessation of the lachrymatory action and acrid odor of the aldehyde. If sulfonation is conducted at room temperature, and higher (about 50-60°), considerable darkening of the reaction mixture is observed due to the formation of resinous substances. Upon reverse addition of the components, i.e., upon addition of the aldehyde to the dioxane-sulfotrixoide solution, the monosulfo acids do not result, but rather products of higher sulfonation.

The initial products of sulfonation are the dioxane salts of the unsaturated aldehyde sulfo acids. These salts dissolved in dichlorethane and hydrolyze instantly with water. Upon their treatment with a water suspension of barium carbonate, there occurs an exchange reaction in which the barium salts of the corresponding sulfoacids result. The potassium salts are easily obtained from the barium salts by interchange reaction with potassium sulfate. The potassium and barium salts of the acrolein sulfoacids and crotonic aldehyde are hygroscopic; they dissolve very readily in water. Their aqueous solutions are stable, and upon evaporation the salts crystallize out - stable indefinitely. The sulfoacid salts obtained possess unsaturated properties: their aqueous solutions decolorize potassium permanganate instantly, as well as bromine water. The carbonyl group in the aldehyde molecule was preserved in both cases after introduction of the sulfo group. Its presence was easily detected by the silver mirror test. The salts of the sulfo acids likewise reduce Fehling's solution to Cu_2O. Reaction for the carbonyl group was negative in all cases. This should apparently be explained as being due to the effect of a negative substituent, which is the sulfo group.

As a result of the procedures worked out for sulfonation of acrolein and of crotonic aldehyde, in yields of 96 and 75 % of theory, the monosulfoacids of the unsaturated aldehydes, whose salts possess the properties described above, have been obtained. The reactions can be represented in accordance with the following scheme:



where Dix = dioxane.

The position of the sulfo group was demonstrated by oxidizing the potassium salts of the sulfo acids in alkaline medium with potassium permanganate. Among the oxidation products were found carbonic acid, potassium sulfate and oxalic acid, the latter microscopically identified in the form of its calcium salt. Among the oxidation products of the crotonic sulfo acid, acetic acid was not there. As is known, a sulfo group situated at a carbon-carbon double bond is easily split off by oxidizing agents, converting into $SO_4^{=}$ ion [7].

The potassium salts of the sulfo acids are reduced in the presence of Raney nickel, one mole of hydrogen adding. After hydrogenation the salt solutions did not give reactions for the aldehyde group, but still decolorized $KMnO_4$ and bromine water as before. Consequently, the carbonyl group and not the double bond was reduced. Among the oxidation products for the reduced salts were found the same products as upon oxidation of the nonreduced salts. Such a type of hydrogenation is one more proof that the SO_3H- group is located at the double bond, which in the case given is shielded by the negative substituent.

The inactivity of a double bond which carries a negative substituent (-CHO, -SO_3H, or other) toward addition reactions is not an isolated case, but as a rule a double bond of such character is extremely difficult to reduce. But it should also be explained that many unsaturated carbonyl compounds do not add hydrogen, halogens, so forth, to the double bond, or that reactions proceed only with difficulty and with complications. For example, the the reduction of crotonic aldehyde with aluminum isopropoxide [8] proceeds without touching the double bond. With the divinylsulfoacid, obtained by direct sulfonation of divinyl, only one bond hydrogenates in the presence of nickel; the second to which is attached the SO_3H-group, remains untouched [9].

The free sulfoacids of the unsaturated aldehydes were not found to be stable to the same degree. The acrolein sulfoacid is stable in aqueous solution for an indefinite period. But when it is concentrated by evaporation on a water bath, rapid darkening of the liquid occurs, and the sulfo group is split off, with sulfuric acid formation. By cautious evaporation at room temperature in a vacuum dessicator, it is possible to isolate the free sulfoacid in the form of crystals, melting with decomposition at 98°. The crotonic sulfoacid is much less stable. When isolated in the free state, it decomposes in aqueous solution within a few hours, forming a resinous mass and sulfuric acid.

EXPERIMENTAL

Dioxane-Sulfotrioxide Synthesis. 15 g (0.19 mole) of sulfuric anhydride was dissolved in 80 ml of dry dichlorethane, cooled in ice water. 16.5 ml (0.19 mole) of dioxane dried and distilled over KOH, was added in small portions, while stirring and cooling to 0°, to the SO_3 solution. The white, crystalline dioxane-sulfotrioxide precipitated immediately, which was still considerably dissolved in proportion to the amount of dichlorethane added.

Sulfonation of Acrolein. Freshly-prepared dioxane-sulfotrioxide solution was added in portions to a solution of 10.5 g (0.19 mole) of freshly-prepared acrolein (b.p. 52°) in 20 ml of dioxane, with stirring and cooling to 0°, whereupon rapid reaction occurred. In proportion to the dioxane-sulfotrioxide addition, the colorless solution became colored, acquiring the color of tea by the end of the reaction. During sulfonation negligible heat evolution was observed. After completing the addition of sulfonating agent, the reaction mixture was left at room temperature for 20-30 minutes. There appeared a small precipitae on the bottom of the flask, apparently the dioxane salt of the acrolein sulfoacid. Neither odor nor lachrymatory action was observed in the reaction mixture.

Acrolein Sulfoacid Salts. The initial sulfonation product was treated with a water suspension of 40 g of $BaCO_3$ in 200 ml of water to give a neutral reaction. After separation of $BaSO_4$, the light-yellow filtrate gave an abundant reaction for the barium ion and decolorized $KMnO_4$ instantly, as well as bromine water. The filtrate was evaporated on a water bath and 40 g of the barium salt was obtained.

0.1551 g substance: 0.0810 g $BaSO_4$. Found %: Ba 30.74. $C_3H_3O_4SBa_{1/2} \cdot H_2O$. Calculated %: Ba 30.96.

In order to remove the water of crystallization, the barium salt was boiled with benzene and then dried in a vacuum dessicator over sulfuric acid to a constant weight.

7.800 mg substance: 4.440 mg $BaSO_4$. Found %: Ba 33.50. $C_3H_3O_4SBa_{1/2}$. Calculated %: Ba 33.70.

The potassium salt was obtained by precipitating a hot solution of the barium salt with an equivalent quantity of potassium sulfate solution. The filtrate, containing the K-salt, likewise readily decolorized $KMnO_4$ solution and bromine water.

0.1662 g substance: 0.0816 g K_2SO_4. 6.737 mg substance: 5.210 mg CO_2; 1.002 mg H_2O. Found %: K 22.27; C 21.10; H 1.66. $C_3H_3O_4SK$. Calculated %: K 22.44; C 20.68; H 1.74.

A warmed solution of the acrolein sulfoacid potassium salt gave a silver mirror reaction (occasionally the silver precipitated in the form of a black precipitate) and reduced Fehling's solution.

6 g (0.034 moles) of the acrolein sulfoacid potassium salt in 60 ml of water was placed into a flask with 6 g of nickel prepared according to Raney. During 5 hours shaking at room temperature, 750 ml (about 0.034 mole) of hydrogen was consumed. Further absorption was practically nil. The reduced salt solution did not have a hydrogen sulfide odor, nor mercaptan odor, but decolorized $KMnO_4$ and bromine water as before. The silver mirror and the Fehling tests gave negative results.

3 g of the acrolein sulfoacid potassium salt in 50 ml of water was placed in a long-necked flask for oxidation, made slightly alkaline with potassium hydroxide and 11 g of finely powdered $KMnO_4$ added in small portions with continuous shaking. The oxidation proceeded with considerable heat and CO_2 evolution. To complete reaction, the flask contents were heated on a water bath for 2 hours (until the permanganate color disappeared). After removal of the manganese dioxide, the contents were evaporated to a small volume and treated with calcium nitrate solution. Acetic acid was added in slight excess to the white precipitate. Simultaneously a portion of the precipitate dissolved with CO_2 evolution (carbonates). The remaining precipitate was analyzed under the microscope. For this purpose a drop of the suspension was placed on a slide, mixed with a drop of hydrochloric acid and left until crystals formed on the glass slide. At 8 to 15 magnifications under the microscope a mixture of calcium sulfate and calcium oxalate crystals were distinctly observed. Upon oxidizing the reduced K-salt under similar conditions, calcium oxalate crystals were also found among the oxidation products under the microscope.

Sulfonation of Crotonic Aldehyde. 15.75 g (0.225 mole) of freshly-distilled crotonic aldehyde (b.p. 103-104°) was sulfonated according to the method described above with 37.8 g (0.225 mole) of dioxane-sulfotrioxide. After appropriate treatment with 50 g of barium carbonate, 36.5 g of the barium salt was isolated.

0.3648 g substance: 0.1968 g $BaSO_4$. Found %: Ba 31.71. $C_4H_5O_4SBa_{1/2}$. Calculated %: Ba 31.53.

The K-salt obtained likewise corresponded to the monosulfoacid:

0.3745 g substance: 0.1767 g K_2SO_4. 9.040 mg substance: 8.350 mg CO_2; 2.145 mg H_2O. Found %: K 21.17; C 25.20; H 2.65. $C_4H_5O_4SK$. Calculated %: K 20.77; C 25.52; H 2.68.

The crotonic sulfoacid potassium salt solution precipitated silver in the form of a mirror upon heating with an ammoniacal solution of $AgNO_3$; with Fehling's solution red Cu_2O precipitated.

3 g (0.02 mole) of the crotonic sulfoacid in 30 ml of water was hydrogenated in a long-necked flask with 3 g of Raney nickel. During 4 hours, 357 ml (about 0.02 mole) of hydrogen was absorbed. The filtrate did not give a silver mirror test, and did not reduce Fehling's solution, but decolorized $KMnO_4$ and bromine water.

2 g of the K-salt was dissolved in 50 ml of water and 7 g of $KMnO_4$ was added in portions. Oxidation

proceeded with strong heat evolution in the reaction mixture. To complete the reaction, the mixture was heated on a water bath until the $KMnO_4$ color disappeared. Among the oxidation products, after appropriate treatment, there was found and identified calcium oxalate under the microscope by the crystal form. The K-salt reduced in the presence of nickel, and then oxidized, likewise gave oxalic acid.

SUMMARY

1. Dioxane-sulfotrioxide is found to be a good sulfonating agent for acrolein and crotonic aldehyde.

2. Sulfocompounds of acrolein and of crotonic aldehyde were obtained and described for the first time.

3. The structures of the newly-obtained acrolein sulfo acid and crotonic aldehyde sulfo acid have been determined.

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* See Consultants Bureau translation page 775.

HYDROGEN ADDITION TO ACETYLENE DERIVATIVES

THE CATALYTIC HYDROGENATION OF THE METHYL AND ETHYL ETHERS OF 2,7-DIMETHYLOCTADIINE-3,5-DIOL-2,7*

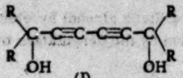
Yu. S. Zalkind** and Z. N. Kolyaskina

In the preceding works by one of the authors [1] on the addition of hydrogen to acetylene γ-glycols and their ethers, it was demonstrated that hydrogen addition to the above-mentioned compounds proceeds differently in the presence of platinum than in the presence of palladium.

In the presence of platinum black, the addition of 4 hydrogen atoms proceeds uniformly to the saturated compound. In the presence of palladium, however, there is noted a characteristic hydrogenation course, namely: 2 hydrogen atoms add rapidly to the molecule, and then the reaction rate decreases considerably. The selective action of the catalyst is evident—while acetylene glycol (ether) is present, ethylene does not enter into the reaction.

It was demonstrated [2], that the hydrogenation rate for the dimethyl and diethyl ethers is greater than for their corresponding glycol, however, with an increased weight in alkoxyl groups the hydrogenation rate decreases considerably.

It was of interest to investigate the properties of the diacetylene glycols and ethers and to compare their conformities to an established rule defined for the monoacetylene glycols and ethers. Derivatives with two triple bonds in the conjugated position are almost uninvestigated. Only isolated works [3,4] are known on the hydrogenation of glycols of type (I):



(I)

The ethers of the same series have not been investigated at all. The authors [3] who investigated these glycols indicate that the diacetylene glycol of 2,7-di-p-tolyloctadiyne-3,5-diol-2,7 conforms to an established pattern for the monoacetylene glycols when hydrogenated in the presence of palladium; Yu. S. Zalkind and L.F. Chelpanova [4] note the absence of such regularities for 2,7-dimethyloctadiyne-3,5-diol-2,7. Our research on the hydrogenation of the glycol of 2,7-dimethyloctadiyne-3,5-diol-2,7 and its ethers have likewise shown that selective hydrogenation, in the presence of palladium, of the diacetylene glycol of 2,7-dimethyloctadiyne -3,5-diol-2,7 and its ethers is absent.

Analysis of the hydrogenation products, after addition of 4 hydrogen atoms for one molecule of the hydrogenated substance to form 2,7-dimethyloctadiyne-3,5-diol-2,7 and its dimethyl and diethyl ethers, has shown that the hydrogenation products are a mixture containing 25-30% of the original diacetylene compound. The authors did not find the diethylene compounds.

The 2,7-dimethyl-2,7-diethoxyoctadiyne-3,5 was investigated in greater detail.

The authors have carried out experiments on hydrogen addition, with intermissions after the absorption of 5 and 6 hydrogen atoms per molecule of hydrogenated substance, and to completion of the hydrogenation. A retardation of the reaction rate is observed after the addition of 6 hydrogen atoms; further addition proceeds very slowly and after addition of about 8 hydrogen atoms hydrogenation practically ceases.

Examination of the hydrogenation products after the addition of 5 and 6 hydrogen atoms, and to completion of the hydrogenation, has demonstrated that in all instances there is present a mixture of products, saturated and unsaturated in composition. The authors were able to isolate a liquid with b.p. 113° at 11 mm (II), and a very small quantity of liquid with b.p. 96-99° at 15 mm (III) from the mixture after addition of 6 hydrogen atoms:

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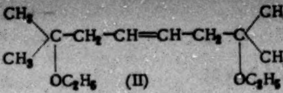
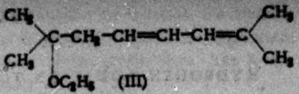
* For the synthesis of ethers of 2,7-dimethyloctadiine 3,5-diol-2,7 see the following article on page 2203.

** Deceased


(II)


(III)

It is possible that after the addition of 4 hydrogen atoms there forms an intermediate hydrogenation product – the acetylene ether, which in its turn after addition of 2 more hydrogen atoms gives the ethylene compound. It is quite probable that by precisely such a reaction course can be explained the retardation of the reaction rate after addition of 6 hydrogen atoms, characteristic for the acetylene bond, the more so that after addition of 6 hydrogen atoms the authors were able to isolate compound (II) in 55-60% yield. The structure of this compound (II) was proven by oxidation, wherein there resulted β-ethoxyisovaleric acid, acetic acid and acetone.

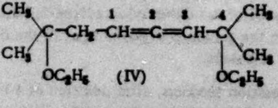
The authors had to determine further whether there was any of the original product in the mixture after addition of 6 hydrogen atoms. For this purpose hydrolysis was carried out, followed by reaction with metallic sodium, according to Bukhovets [5]. The reaction was negative. Consequently the mixture did not contain any of the original diacetylene ether, and by its disappearance might be explained the retardation of the hydrogen addition reaction.

Thus, these data indicate that the addition of hydrogen to diacetylene compounds proceeds in quite a complex manner. Hydrogenation was carried out in the presence of platinum black. Analysis of the hydrogenation products for 8 hydrogen atoms and for complete hydrogenation indicated that they likewise represent a mixture, saturated and unsaturated in composition.

After addition of 8 hydrogen atoms there was isolated from the mixture a liquid of b.p. 122-124° at 15 mm to the amount of 58-60% which was found to be similar in its structure to the full ether of the ethylene glycol (II) and to the aromatic mixture of b.p. 96-99° at 15 mm which was obtained in 12-15% yield and which was found to be similar to substance (III). The structure of this substance was proven by oxidation, wherein β-ethoxyisovaleric acid, oxalic acid, acetone and traces of acetic acid were obtained, which indicates that the substance is the ethyl ether of 2,7-dimethyl-octadiene-4,6-ol-2.

A. I. Lebedeva [6] obtained the corresponding diene alcohol by electrolytic hydrogenation of 2,7-dimethyl-octadiyne-3,5-diol-2,7, and she explains its formation by the dehydration of the ethylene glycol of 2,7-dimethyl-octene-4-diol-2,7.

It is possible that in our case there likewise occurs dealcoholation of the ether of this glycol (II), which leads to the formation of the ether of 2,7-dimethyl-octadiene-4,6-ol-2 (III). It is possible, however, that the formation of compounds with one ethoxyl group proceeds differently. If the hydrogen addition proceeds in such a manner that it forms an intermediate product of the allene type (IV):

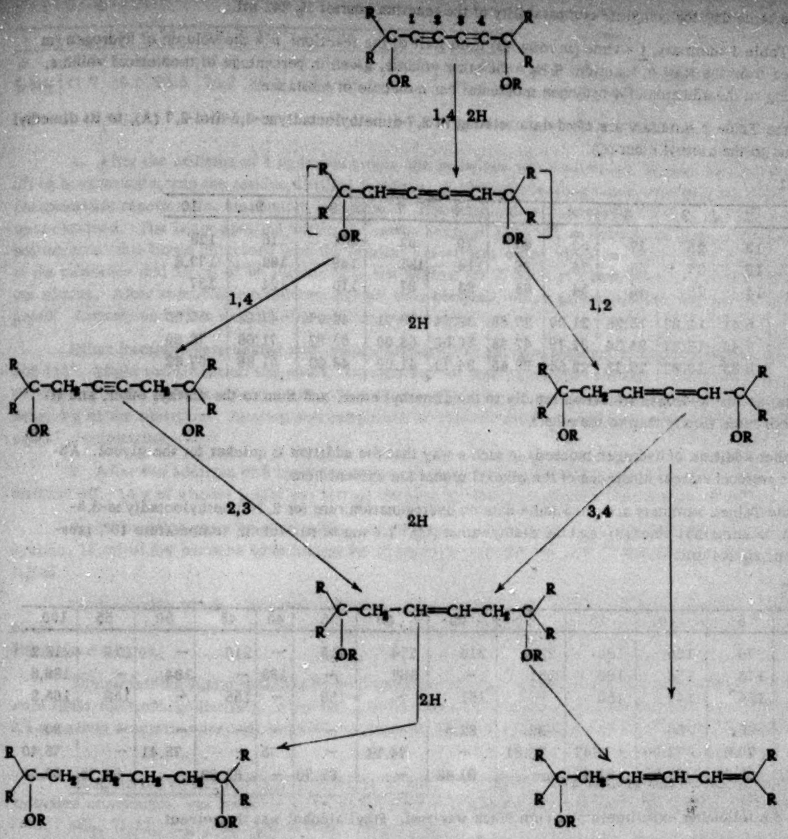

(IV)

then the presence of double bonds near to each other, and the oxygen atom of the ethoxyl group will produce an effect upon the fourth carbon atom which will promote the breaking away of the ethoxyl group. Possibility for the formation of the diethylene product is not excluded, although the authors failed to isolate it, regardless of the many experiments performed according to Diels-Alder.

Therefore, on the basis of the literature data [7,8,9,10] and the experimental data obtained by the authors, we consider it possible to assume the catalytic hydrogenation scheme to take the following form: (see next page)

Upon hydrogenation of 2,7-dimethyloctadiyne-3,5-diol-2,7 and its dimethyl and diethyl ethers in the presence of platinum, a certain analogy with the monoacetylene glycols and their ethers is observed during the course of hydrogenation.

As with the monoacetylene compounds, the addition of 8 hydrogen atoms proceeds with a smooth retardation in the rate of hydrogen addition, and the reaction does not terminate at this point, but rather proceeds further although very slowly to the addition of 10 hydrogen atoms, after which the hydrogenation practically ceases.



The analogy is also observed with variation in the character of hydrogenation in the presence of platinum and palladium, and this difference is evident not only in the hydrogenation course, but also in the number of hydrogen atoms added.

There is likewise observed in the hydrogenation rate of the glycol and the ethers an analogy with the monoacetylene compounds. Thus, the full methyl and ethyl ethers of the acetylene γ-glycols hydrogenate more rapidly than the glycol alone [2].

The diacetylene glycol ethers studied by the authors likewise add hydrogen more rapidly at the first moment than the glycol; but the difference between the hydrogenation courses of ethers and of glycol are insignificant. The quantity of catalyst affects only the hydrogenation rate.

EXPERIMENTAL

I. Catalytic Hydrogenation of 2,7-Dimethyloctadiyne-3,5-diol-2,7 and its Dimethyl and Diethyl Ethers.

The colloidal palladium was prepared on gum arabic. 0.0025 mole of the substance dissolved in 50 ml of water and 0.8 mg of palladium were taken for each experiment. The tests were carried out at 15°, and 757 mm on one and the same day for complete comparability of the reaction course: H_2 242 ml.

In Table 1 summary, t = time (in minutes) from start of the reaction; ν = the volume of hydrogen (in ml) absorbed from the start of reaction; $\% H_2$ = the same volume, given in percentage of theoretical volume, corresponding to the addition of 4 hydrogen molecules per molecule of substance.

In the Table 1 summary are cited data relating to 2,7-dimethyloctadiyne-3,5-diol-2,7 (A), to its dimethyl ether (B) and to the diethyl ether (C).

TABLE 1

t		1	2	3	4	5	6	7	8	9	10
ν	A	13	25	37	53	67	79	92	104	116	128
	B	19	37	55	74	96	114	131	149	162	173.8
	C	14	26	40	54	68	83	97	110	124	137
$\% 4H_2$	A	5.41	10.33	15.28	21.90	27.68	32.64	38.01	42.97	47.98	50.00
	B	8.40	16.37	24.34	32.79	42.48	50.00	58.00	65.92	71.68	76.90
	C	5.85	10.87	16.73	22.55	28.45	34.73	41.00	46.02	51.88	57.32

Thus, at first hydrogen adds most rapidly to the dimethyl ether, and then to the diethyl ether, and it adds to glycol more slowly than to the ethers.

Further addition of hydrogen proceeds in such a way that the addition is quicker for the glycol. Apparently the stereochemical hindrances of the alkoxyl groups are evident here.

In the Table 2 summary are cited some data on hydrogenation runs for 2,7-dimethyloctadiyne-3,5-diol-2,7 (A), its dimethyl ether (B), and the diethyl ether (C). 1.6 mg of palladium, temperature 16°, pressure 750 mm; H_2 244 ml.

TABLE 2

t		5	10	15	20	25	30	35	40	45	50	55	100
ν	A	70	136	180	202	210	214	215	–	216	–	217	218.2
	B	173	178	180	181	–	182	–	183	–	184	–	186.6
	C	136	146	150	–	151	–	153	–	156	–	158	165.2
$\% 4H_2$	A	28	56	73	82	82.5	–	–	–	–	–	–	90
	B	70.90	73.00	73.47	73.81	–	74.18	–	75	–	75.41	–	76.40
	C	55.73	61.06	61.47	–	61.48	–	62.70	–	63.93	–	64.75	68.00

For the following experiment platinum black was used. Ethyl alcohol was the solvent.

In the Table 3 summary are cited data for the hydrogenation of 2,7-dimethyloctadiyne-3,5-diol-2,7 (A) and its diethyl ether (B) in the presence of 0.1 g of platinum at 16°; 753 mm; H_2 246 ml (from calculation for two triple bonds).

Hydrogenation runs for the dimethyl ether of the same glycol also give analogous results. One of them is cited in Table 4.

0.2684 g of dimethyl ether, 0.1 g of platinum, 35 ml of alcohol, temperature 15°, pressure 753: H_2 133 ml.

TABLE 3

t		5	10	15	20	25	50	75	100	500	860	1200
ν	A	11	20	25	30.2	35.8	61.2	84.4	103	195.8	–	245
	B	12	21	27	32.8	38.4	64	85.6	108.6	205	246	
$\% 4H_2$	A	4.5	8.1	10.1	11.9	14.5	24.8	34.3	41.8	79.1	–	99.6
	B	4.8	8.5	10.9	13.3	15.6	26.0	34.7	44	83.3	100	

Hydrogenation proceeds further, but very slowly.

TABLE 4

t	5	10	15	20	25	50	75	85	90	95
v	15.6	25.4	34	41.8	49	82	113.2	123.8	129	133
$\% 4H_2$	11.7	19.0	25.5	30.6	36.8	61.6	85.1	93	97	100

Hydrogenation also proceeds further.

II. Investigation of the Hydrogenation Products from 2,7-Dimethyl-2,7-diethoxyoctadiyne-3,5 Using Palladium.

1. After the addition of 4 hydrogen atoms, the palladium was precipitated, filtered off, the alcohol distilled off on a water bath, and the residue distilled in vacuo. A pleasant-smelling liquid was obtained which gave all the characteristic reactions for unsaturated compounds. The mixture was fractionally distilled at 8 mm; three fractions were obtained. The latter distilled within the narrow range of 113-115°, and contained 25% of the total mixture; in boiling point this liquid coincided with the original diacetylene ether, which was confirmed by hydrolysis: 0.82 g of the substance and 20 ml of 7% sulfuric acid and heating for 15 hours at a bath temperature of 70-75° with vigorous stirring. After appropriate treatment crystals were obtained, which gave a positive reaction for diacetylene glycol. Consequently this was the original diacetylene ester.

Other fractions were heated with maleic anhydride in benzene solution in sealed ampoules for 20 hours at 105-115°. Slight resinification was noted. Crystals did not precipitate upon cooling. The same was carried out on the hydrogenation product obtained after the addition of 5 hydrogen atoms. 2 g of maleic anhydride, 15 ml of benzene, 4 g of the substance. Heating was carried out at 105-115° for 16 hours. Upon cooling there was no sign of crystal precipitation.

2. After the addition of 6 hydrogen atoms the palladium was precipitated, filtered off, and the alcohol distilled off. 14 g of viscous liquid was left which gave all the characteristic reactions for unsaturated compounds.

A condensation reaction with maleic anhydride was carried out. 4 g of the substance, 2 g of maleic anhydride, 15 ml of dry benzene were heated for 10 hours at 110, 120 and 125°. Condensation products were not obtained.

To determine whether or not there was the original diacetylene ether among the addition products, 0.5 g of the liquid was hydrolyzed with 7% sulfuric acid solution. The hydrolysis product gave a negative result for the diacetylene glycol.

The remaining liquid obtained by hydrogenation was fractionally distilled to obtain three fractions, which were again fractionally distilled. After the fifth fractional distillation there was obtained: I) 85-95° (14 mm) – 0.1 g (strong aromatic odor); II) 101-106° – 1.2 g; III) 106-113° (13 mm) – 0.2 g; IV) 113° (11 mm) – 4.85 g.

Examination of the 113° b.p. fraction at 11 mm. The liquid, possessing properties characteristic for unsaturated compounds, was insoluble in water but soluble in many organic solvents: d_{17}^{17} 0.8669; d_4^{17} 0.8652; n_D^{17} 1.4551. Found: MR_D 71.11. $C_{14}H_{28}O_2$. Calculated: MR_D 69.67.

0.1178 g substance: 0.3177 g CO_2; 0.1300 g H_2O. 0.1391 g substance: 0.3756 g CO_2; 0.1552 g H_2O. Found %: C 73.55, 73.63; H 12.26, 12.40. $C_{14}H_{28}O_2$. Calculated %: C 73.68; H 12.28. 0.1346 g substance; 15.38 g benzene: Δt 0.20°. 0.1162 g substance; 7.9147 g benzene: Δt 0.34°. Found: M 224.4, 221.9. $C_{14}H_{28}O_2$. Calculated: M 228. 0.1480 g substance: 0.2835 g AgI. Found %: OC_2H_5 37.3. $C_{10}H_{18}(OC_2H_5)_2$. Calculated %: OC_2H_5 39.5.

Oxidation of the 113° b.p. fraction at 11 mm. To determine the structure of the given substance, its oxidation with potassium permanganate was carried out, calculating on the basis of one double bond. 560 ml of 1% $KMnO_4$ solution was added with very rapid stirring to 30 g of water and 4 g of the substance. Oxidation continued for 8 hours.

After completion of reaction, the manganese dioxide was filtered off and washed with hot water. After cooling, the manganese dioxide and the filtrate were repeatedly extracted with ether. From the neutral products the acetone in the form of its 2,4-dinitrophenylhydrazone was identified, m.p. 122° (literature data = 126°) The remaining portion of neutral products was not examined due to the small amount involved.

The aqueous solution was steamed off and acidified with 10% H_2SO_4 solution. The acids were extracted three times with ether. The silver salts were obtained from the ammonium salt by fractional precipitation with silver nitrate.

Fraction I: 0.1155 g substance: 0.0484 g Ag. Found %: Ag 41.90. Fraction II: 0.0675 g substance: 0.0282 g Ag. Found %: Ag 41.77. $C_7H_{13}O_3Ag$. Calculated %: Ag 42.68.

The aqueous solution was extracted a second time with ether for 50 hours. The liquid obtained after distilling off the ether was heated with moist silver oxide. The silver salt obtained was analyzed:

0.0398 g substance: 0.0262 g Ag. Found %: Ag 65.83. $C_2H_3O_2Ag$. Calculated %: Ag 64.68.

Thus, β-ethoxyisovaleric acid and acetic acid were the results of the oxidation.

3. After addition of 7 hydrogen atoms in the presence of palladium, the hydrogenation practically stops, since more hydrogen adds extraordinarily slowly.

The liquid obtained was likewise a mixture and distilled in the range 110-118° at 10-13 mm. 4 fractions were obtained. All four fractions decolorized bromine water and potassium permanganate solution.

III. Investigation of the Hydrogenation Products of 2,7-Dimethyl-2,7-Diethoxyoctadiyne-3,5 with Platinum.

1. After the addition of 8 hydrogen atoms, the hydrogenation products from 2,7-dimethyl-2,7-diethoxyoctadiyne-3,5 were filtered off from the platinum and the alcohol was distilled off. 20 g of a viscous colorless liquid of pleasant aromatic odor remained. This liquid gave all of the reactions characteristic for unsaturated compounds. Several tests with maleic anhydride were set up, which gave negative results. The liquid was fractionally distilled under vacuo. After a fourth distillation at 15 mm, 5 fractions were obtained. I) 94-96° – several drops; II) 96-99° – 1 g – 11.75%; III) 103-107° – 1.6 g – 19%; IV) 114-118° – 0.9 g – 10.6%; V) 122-124° – 5 g – 58.65%.

All fractions decolorized bromine water and potassium permanganate solution. Elementary analysis data for the fractions of b.p. 103-107° and 114-118° indicated that these liquids are mixtures. Fraction II with b.p. 96-99°, and with b.p. 122-124° were examined in detail.

Investigation of the liquid with b.p. 96-99° at 15 mm. Colorless, very pleasant-smelling liquid, insoluble in water, readily soluble in many organic solvents:

d_{18}^{18} 0.8098; d_4^{18} 0.8096; n_D^{18} 1.4509. Found: MR_D 60.26. $C_{12}H_{22}O$. Calculated: MR_D 58.53.

0.1031 g substance: 0.2941 g CO_2; 0.1198 g H_2O. 0.1333 g substance: 0.3815 g CO_2; 0.1545 g H_2O. Found %: C 77.78, 78.05; H 12.91, 12.87. $C_{12}H_{22}O$. Calculated %: C 79.12; H 12.10. 0.1175 g substance; 7.02 g benzene: Δt 0.46°. 0.1580 g substance; 7.62 g benzene: Δt 0.585°. Found: M 186, 181. $C_{12}H_{22}O$. Calculated: M 182. 0.1740 g substance: 0.2134 g AgI. 0.1068 g substance: 0.1292 g AgI. Found %: OC_2H_5 23.5 23.6. $C_{10}H_{17}(OC_2H_5)$. Calculated %: OC_2H_5 24.7.

Negative reaction with maleic anhydride.

Oxidation of the 96-99° b.p. fraction at 15 mm. 1 g of the substance was oxidized with 1% $KMnO_4$ solution. Oxidation was complete after 20 hours. After the oxidation, the manganese dioxide was filtered off and washed with hot water. Soda was added to the solution until the solution was alkaline, and the solution was heated for several minutes, the acetone distilled was characterized in the form of its 2,4-dinitrophenylhydrazone, with m.p. 120°. The acids were converted to the silver salts.

Fraction I 0.0638 g substance: 0.0270 g Ag. Found %: Ag 42.32. Fraction II 0.0678 g substance: 0.0289 g Ag. Found %: Ag 42.62. $C_7H_{13}O_3Ag$ Calculated %: Ag 42.68.

This corresponds to ethoxyisovaleric acid. From the aqueous solution remaining after the extraction of ethoxyisovaleric acid with ether, additional extraction was carried out in the extractor for 50 hours, at which time oxalic acid crystals were obtained, which were converted into the corresponding calcium salt.

On the basis of the data obtained, the structure, 2,7-dimethyl-7-ethoxy-octadiene-2,4 ester, should be assigned to the substance with b.p. 96-99° at 15 mm.

Examination of the liquid with b.p. 122-124° at 15 mm. Colorless, oily liquid with very faint pleasant odor, insoluble in water but soluble in many organic solvents. Gave all of the reactions for unsaturated compounds:

d_{22}^{22} 0.8643; d_4^{22} 0.8633; n_D^{22} 1.4556. Found: MR_D 71.27. $C_{14}H_{28}O_2$. Calculated: MR_D 69.77.

0.1154 g substance: 0.3122 g CO_2; 0.1296 g H_2O. 0.1423 g substance: 0.3839 g CO_2; 0.1546 g H_2O. Found %: C 73.78, 73.58; H 12.47, 12.07. $C_{14}H_{28}O_2$. Calculated %: C 73.68; H 12.28. 0.1671 g substance: 6.46 g benzene: Δt 0.58°. 0.2292 g substance; 8.13 g benzene: Δt 0.66°. Found: M 228, 219. $C_{14}H_{28}O_2$. Calculated: M 228. 0.1653 g substance: 0.3345 g AgI. 0.1550 g substance: 0.3102 AgI. Found %: OC_2H_5 39.0, 38.5. $C_{10}H_{18}(OC_2H_5)_2$. Calculated %: OC_2H_5 39.5.substance.

Oxidation of the fraction with b.p. 122-124° at 15 mm. 3.5 g of the substance was oxidized with 1% $KMnO_4$ solution. Upon vigorous mechanical stirring oxidation proceeded. 500 ml of the solution was added dropwise over a period of 4.5 hours. Further treatment was carried out by the usual procedures.

Ethoxyisovaleric acid, acetic acid and acetone resulted upon oxidation. Consequently the substance with b.p. 122-124° at 15 mm has the same structure as the 113° at 11 mm fraction, i.e., corresponds to 2,7-dimethyl-2,7-diethoxyoctene-4.

2. After absorption of 10 hydrogen atoms, hydrogen addition practically ceased. Upon examination of the hydrogenation products it was found that the liquid obtained distilled in the range 60-122° at 16-17 mm. 4 fractions were obtained. They all decolorized bromine water and potassium permanganate; all gave positive reactions for the ethoxyl group.

The fractions with b.p. 92-97° had n_D^{18} 1.4494; this is close to the fraction 96-99° at 15 mm. The elementary analysis for carbon (78.75) is likewise close to the fraction 96-99° at 15 mm.

All of these data attest to the fact that in this case there is also obtained a mixture of substances in various stages of reduction.

SUMMARY

1. A study of the catalytic hydrogenation of 2,7-dimethyloctadiyne-3,5-diol-2,7 and its dimethyl and diethyl ethers, has demonstrated that these compounds behave differently toward hydrogenation in the presence of platinum as against palladium.

2. It was found that in the presence of colloidal palladium there is no observable break in the hydrogenation rate of the ethers after the addition of 4 hydrogen atoms. The retardation of reaction rate is observed after addition of 6 H, and the reaction then proceeds with unusual slowness to 8 H. All of this points to the absence of selective hydrogenation of the triple bonds for the diacetylene glycols and their ethers.

3. It was demonstrated that the hydrogenation products after addition of 4, 5, and 6 hydrogen atoms per molecule of substance are found to be a mixture of varied composition.

4. Catalytic addition of hydrogen in the presence of platinum proceeds uniformly with slowing down at 8 hydrogen atoms; further addition proceeds with great slowness, and after 10 atoms the hydrogenation practically ceases. The hydrogenation products with platinum are likewise found to be a mixture.

5. As the result of catalytic hydrogenation there were obtained new compounds not described in the literature: 2,7-dimethyl-2,7-diethoxyoctene-4 and 2,7-dimethyl-7-ethoxyoctadiene-2,4.

6. On the basis of the literature and from the experimental data, a possible scheme for hydrogen addition to diacetylene ethers has been proposed.

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* See Consultants Bureau English Translation, p. 1281.

6.1254 g substance in 0.1958 g [illegible]

Found %: C 72.18; 72.36; H 12.44; 12.40. $C_{18}H_{34}O_2$. Calculated %: C [illegible]; H [illegible]. [illegible] substance: 5.48 g naphthalene; Δt 0.58°. 0.3236 g substance; 4.14 g camphor; Δt 9.78°. Found: M 228; 214. $C_{18}H_{34}O_2$. Calculated: M 228. 0.4652 g substance: [illegible] 0.3153 g AgI. Found %: OCH_3 [illegible]. $C_{12}H_{20}O_2$ [illegible]. Calculated %: OCH_3 [illegible].

Oxidation of the reaction with 1% $KMnO_4$ at 15 mm. 1.5 g of the substance was oxidized with 4% $KMnO_4$ solution. [illegible] 3000 ml [illegible] was added dropwise over a period of 4.5 hours. Further treatment was carried out by the usual procedure.

Tricarboxylic acid, acetic acid, and acetone [illegible] with b.p. 122-124° at 15 mm has the same structure as the [illegible]

3. After absorption of 10 hydrogen atoms hydrogen addition practically ceased. Upon examination of the hydrogenation products it was found that the [illegible] fractions were obtained. They all decolorized bromine water and [illegible] gave positive reactions for the carbonyl group.

The fraction with b.p. [illegible] at 15 mm [illegible] elementary analysis for carbon [illegible]

Each of these fractions [illegible] is a mixture of substances in various stages of reduction.

SUMMARY

1. A study of the catalytic hydrogenation of [illegible] and diethyl ethers has demonstrated that [illegible] toward hydrogenation in the presence of platinum as against palladium.

2. It was found that in the presence of colloidal palladium [illegible] positions [illegible] of the atoms after the addition of 4 hydrogen atoms. [illegible] after the addition of 6 H [illegible] owing to the absence of selective hydrogenation of the double bonds [illegible]

3. It was demonstrated that the [illegible] product after addition of 6 H and 4 hydrogen atoms per molecule of substance was found to be a mixture of [illegible] composition.

4. Catalytic addition of hydrogen in the presence of platinum proceeded uniformly, with slowing down at 6 hydrogen atoms; further addition proceeds very slowly, however, and after 10 atoms the hydrogenation practically ceases. The hydrogenation products with platinum [illegible] were found to be a mixture.

5. As the result of [illegible] hydrogenation there were obtained [illegible] not described in the literature: [illegible]

6. On the basis of the literature and from the experimental data, a [illegible] scheme for hydrogenation to [illegible] has been proposed.

LITERATURE CITED

[1] Yu. S. Zal'kind, [illegible]

Received September 15, 1953

* See Consultants Bureau English Translation, p. [illegible]

THE SYNTHESIS OF ETHERS OF 2,7-DIMETHYLOCTADIYNE-3,5-DIOL-2,7

Yu. S. Zalkind* and Z. N. Kolyaskina

In a work by one of the authors [1] an assumption was made that ethers of tertiary acetylenic alcohols can condense like tertiary acetylenic alcohols [2] into the diacetylene ethers, in the presence of cuprous chloride.

3-Methyl-3-ethoxybutine-1 served as the object of investigation. The condensation was carried out in alcoholic solution in the presence of cuprous chloride, which was taken in the quantity of 15 g for 1 g of initial ether, and was dissolved beforehand in an aqueous solution of ammonium chloride. A few drops of concentrated sulfuric acid was added to the reaction mixture. The reaction was carried out with mechanical stirring and air was simultaneously passed through, and at the end —oxygen. After filtering off the condensation product, extraction was made with ether. A viscous oily liquid was obtained in a yield of 66%, with b.p. 91-96° at 6 mm, d_{20}^{20} 0.9001, n_D^{20} 1.4794, MR_D 69.78. However, the liquid was not investigated in detail.

In this work our aim was to study in more detail the conditions for carrying out the condensation reaction, and likewise to investigate more thoroughly the compounds resulting after condensation, and to prove their structure.

3-Methyl-3-methoxybutine-1 and 3-methyl-3-ethoxybutine-1 served as starting compounds, which were obtained by splitting the monoethers of 2,5-dimethylhexine-3-diol-2,5.

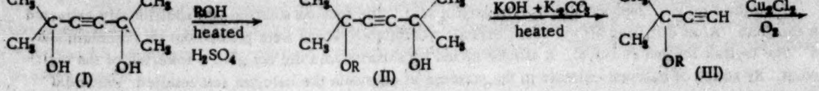
Conditions for carrying out the condensation to diacetylene ethers were changed somewhat. Hydrochloric acid was excluded from the reaction, and the cuprous chloride was taken in the ratio of 1 g per 1 gram of original substance, and isolation of the condensation products was carried out by treatment of the reaction mixture with 5-7% sulfuric acid with subsequent extraction with ether.

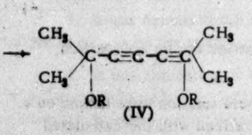
In a great number of experiments it was demonstrated that the condensation reaction can also proceed in the absence of solvent.

As the result of certain modifications in the condensation procedures, and with further treatment, we were able to achieve a condensation product yield of up to 85%.

2,5-Dimethylhexine-3-diol-2,5 (I) was synthesized by the method of Zh. I. Iotsich [3]. The monomethyl and monoethyl ethers of 2,5-dimethylhexine-3-diol-2,5 (II) were obtained by the method of Sh. Mamedov [4].

In the presence of a mixture of powdered potassium hydroxide and potash while heating [5], the obtained ethers were split into the acetone and the ethers of the acetylenic alcohol (III), which condensed into the diacetylenic ethers (IV).





R = CH_3 or C_2H_5.

In this way the authors obtained 2,7-dimethyl-2,7-dimethoxyoctadiyne -3,5 liquid with b.p. 105-106° at 10 mm (this ether has been isolated by the authors for the first time) and the 2,7-dimethyl-2,7-diethoxyoctadiyne 3,5 liquid with b.p. 119-120° at 10 mm. Their structure was proven by oxidation, upon which alkoxyisobutyric acid and oxalic acid resulted, and the glycol resulted upon hydrolysis. It appeared of interest to the authors to investigate the behavior of these ethers toward ethylmagnesium bromide while heating. At the same time the hydrocarbon, 3,3,8,8-tetramethyldecadiine-4,6 was obtained.

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EXPERIMENTAL

I. 2,7-Dimethyl-2,7-diethoxyoctadiyne-3,5.Synthesis. 8 g of cuprous chloride and 16 g of ammonium chloride in 40 ml of distilled water were added to a flask equipped with two outlets into which were placed a dropping funnel and a gas outlet tube equipped with mechanical stirrer. To the solution obtained was added dropwise over a period of 1.5-2 hours, 7.2 g of the ethyl ether of dimethylacetylenecarbinol dissolved in 80 ml of ethanol. Oxygen was simultaneously passed through the agitated mixture (one may use air).

Reaction proceeded for 5-6 hours. After standing 10-12 hours, the solution was poured off from the precipitate, extracted several times with ether, at the same time a small amount of 5-7% sulfuric acid being added to remove the cupric chloride residue. The ether solution was then shaken 2-3 times with the sulfuric acid solution and was washed several times with water to remove sulfuric acid. The precipitate and the wash waters were again re-extracted 3-4 times with ether, and the ether extraction treated in the same manner; it was combined with the first and dried over sodium sulfate. After a second fractional distillation in vacuo at 10 mm, one fraction with b.p. 119-120° was obtained in the amount of 6 g.

This viscous colorless liquid (which turns slightly yellow upon standing) possessed a faint pleasant odor, was insoluble in water but soluble in benzene, alcohols, chloroform and other organic solvents, decolorized bromine water, potassium permanganate, and did not react with ethylmagnesium bromide under the usual conditions:

d_4^{20} 0.8897; d_4^{17} 0.8916; n_D^{20} 1.4656; n_D^{17} 1.4686. Found: MR_D 69.04; MR_D 69.19. $C_{14}H_{22}O_2$. Calculated: MR_D 66.13 0.1295 g substance: 0.3600 g CO_2; 0.1141 g H_2O. 0.0837 g substance: 0.2319 g CO_2; 0.0737 g H_2O. Found %: C 75.81, 75.56; H 9.87, 9.79. $C_{14}H_{22}O_2$. Calculated %: C 75.67; H 9.90.

0.2946 g substance; 12.79 g benzene: Δt 0.54°. 0.3456 g substance; 10.35 g benzene: Δt 0.79°. Found: M 217.3, 216.9. $C_{14}H_{22}O_2$. Calculated: M 222.

0.1764 g substance: 0.3628 g AgI. 0.1866 g substance: 0.3861 g AgI. Found %: OC_2H_5 39.7, 40.0. $C_{10}H_{12}(OC_2H_5)_2$. Calculated %: OC_2H_5 40.5

For structure determination the substance was oxidized. To 6 g of the liquid under investigation there was gradually added 1 700 ml of a 1% potassium permanganate solution, calculated on the basis of complete rupture of two triple bonds. The oxidation proceeded at room temperature and was complete after 22 hours. The manganese dioxide was filtered off and washed with hot water. The filtrate and manganese dioxide were repeatedly treated with ether to isolate the neutral products. The aqueous solution, after acidification with sulfuric acid was extracted three times with ether (since there occurs hydrolysis of the alkoxyacids upon distillation with water vapor). The ether extraction was dried with sodium sulfate. The ether was not completely distilled. The ether solution was saturated with dry ammonia. The ammonium salt precipitate was dissolved in a few milliliters of water and was precipitated with silver nitrate. The silver salt precipitate was filtered off,washed,dried and analyzed.

Fraction I 0.0468 g substance: 0.0208 g Ag. Found %: Ag 44.44. Fraction II 0.1482 g substance: 0.0680 g Ag. Found %: Ag 45.78. $C_6H_{11}O_3Ag$. Calculated %: Ag 45.18.

Thus,the acid corresponded to ethoxyisobutyric acid. The aqueous solution was additionally extracted in an extractor. After distilling off the ether, crystals precipitated, which were pressed out on porcelain and dried. The crystals melted at 101.5°. A sample mixed with oxalic acid did not give a lowering of the melting point. By action of calcium chloride in the presence of ammonia the calcium salt resulted, which did not dissolve in acetic acid. Therefore, this was oxalic acid.

II. 2,7-Dimethyl-2,7-diethoxyoctadiyne-3,5Hydrolysis. Hydrolysis was carried out for comparison with the monoacetylene ether and for demonstration of structure.

2 g of 2,7-dimethyl-2,7-diethoxyoctadiyne-3,5 and 50 ml of 7% sulfuric acid solution were heated on a water bath to 70-75° with vigorous agitation for 22 hours. The mixture was neutralized with the calculated quantity of soda and extracted with ether. The ether extraction was dried. After distillation of the ether, a viscous, straw-yellow colored liquid remained. The liquid redistilled at 12 mm with a b.p. of 123-125° and was found to be the original compound. An undistillable liquid residue was left in the flask which crystallized. After recrystallization from benzene,snow-white, fine needles were obtained, resembling superficially the glycol of 2,7-dimethyloctadiyne-3,5-diol-2,7. A sample mixed with the glycol did not give depression of the melting point.

In addition, a qualitative tests for diacetylene glycol was carried out according to the method of Bukhovets [6], which gave a positive result. Diacetylene ethers do not give this reaction. Thus diacetylene ethers undergo hydrolysis with extreme difficulty under the above conditions indicated, whereas this reaction proceeds quite easily for the monoacetylene ethers.

III. Reaction of Ethylmagnesium Bromide with 2,7-Dimethyl-2,7-diethoxyoctadiyne-3,5. The organomagnesium compound was obtained beforehand from 4 g of magnesium and 19 g of ethyl bromide. To it was added dropwise 4 g of the diacetylene ether over a period of 2 hours while cooling (with ice water) and with mechanical stirring. The iced bath was then replaced by a water bath with a temperature of 36-40° and the heating was then continued for 10 hours.

After 8-10 hours the reaction mixture was decomposed with 30-35 ml of iced-water, the reaction flask being cooled. The reaction mixture was extracted with ether 5-7 times. The ether extract was dried with sodium sulfate. The ether was distilled off. A viscous, slightly colored liquid, with an odor different from that of the original ether, remained. After a second fractional distillation at 10 mm, two fractions were obtained. Fraction with b.p. 94-96° (1.9 g); decolorized bromine water, potassium permanganate, and gave a negative reaction for the ethoxyl group with hydrogen iodide.

d_4^{19} 0.8308; n_D^{19} 1.4692. Found MR_D 63.46. $C_{14}H_{22}$. Calculated MR_D 62.84. 0.0964 g substance: 0.3082 g CO_2; 0.0967 g H_2O. 0.0840 g substance: 0.2689 g CO_2; 0.0854 g H_2O. Found %: C 87.19, 87.30; H 11.14, 11.30. $C_{14}H_{22}$. Calculated %: C 88.43; H 11.57. 0.1584 g substance; 6.88 g benzene: Δt 0.61°. 0.1541 g substance; 8.26 g benzene: Δt 0.52°. Found: M 188.6, 181.8. $C_{14}H_{22}$. Calculated: M 190.

The substance obtained corresponds to the hydrocarbon, 3,3,8,8-tetramethyldecadiyne-4,6.

IV. 2,7-Dimethyl-2,7-dimethoxyoctadiyne-3,5 Synthesis. The synthesis was carried out under identical conditions. The starting substance was the methyl ether of 3-methyl-butine-1-ol-3:

B.p. 78-80°, d_4^{17} 0.08000; n_D^{17} 1.4020; MR_D 29.81; M 96.

A viscous, colorless liquid was obtained yellowing with time, possessing a faint pleasant odor, soluble in benzene, alcohol, ether and insoluble in water, decolorizing bromine water and potassium permanganate:

B.p. 105-106° at 10 cm; d_{20}^{20} 0.9146; d_4^{20} 0.9122; n_D^{20} 1.4677. Found: MR_D 58.74. $C_{12}H_{18}O_2$. Calculated: MR_D 56.89.

0.1304 g substance: 0.3542 g CO_2; 0.1038 g H_2O. 0.1446 g substance: 0.3927 g CO_2; 0.1179 g H_2O. Found %: C 74.07, 74.06; H 8.89, 9.05. $C_{12}H_{18}O_2$. Calculated %: C 74.22; H 9.27. 0.2967 g substance; 8.88 g benzene: Δt 0.90°, 0.1071 g substance; 6.48 g benzene: Δt 0.44°. Found: M 185.7, 187.9. $C_{12}H_{18}O_2$. Calculated: M 194. 0.1776 g substance: 0.4311 g AgI. 0.1523 g substance: 0.3543 g AgI. Found: % OCH_3 32.6, 31.5. $C_{10}H_{12}(OCH_3)_2$. Calculated %: OCH_3 32.0.

With this liquid analogous reactions were carried out, whereupon results similar to that of 2,7-dimethyl-2,7-diethoxyoctadiyne-3,5 were obtained.

SUMMARY

1. The possibility of condensing ethers of acetylenic alcohols to the diacetylenic ethers of glycols was confirmed in the examples of 2,7-dimethyl-2,7-dimethoxyoctadiyne-3,5 and 2,7-dimethyl-2,7-diethoxyoctadiyne-3,5, which were characterized and their structure demonstrated. The first of these is not described in the literature.

2. It was demonstrated that the diacetylenic ethers obtained hydrolyze under the influence of 7% sulfuric acid, as do the monoacetylenic ethers of the γ-glycols, the former proceeding with greater difficulty.

3. It was demonstrated that by the action of ethylmagnesium bromide, the dimethyl and diethyl ethers of 2,7-dimethyloctadiyne-3,5-diol-2,7 exchange alkoxyl group for alkyl group, the result of which the hydrocarbon 3,3,8,8-tetramethyldecadiyne-4,6 is formed, which has not been described in the literature up to the present time.

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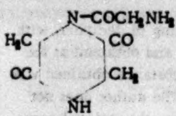
THE STRUCTURE OF ALBUMIN

X. SUBSTITUTED N-AMINOACYL DERIVATIVES OF DIKETOPIPERAZINE

L. N. Akimova and N. I. Gavrilov

After N.D. Zelinsky and V.S. Sadikov, and one of us (N. I. Gavrilov) proved definitely the origin of the cyclic forms of the bonds, the question arose as to the position of this structural unit in the albumin molecule. Different authors have answered this question differently. Thus, V.S. Sadikov and N.D. Zelinsky [1] attempted to visualize a bond between the separate diketopiperazines in the albumin molecule; they named such hypothetical combinations (similar to Fischer's peptides) "peptines" (polypeptines). A model structure, based upon diketopiperazines is known, proposed by Wrinch [2] and named "cyclol" by her.

In treating the question of the albumin molecular structure, many investigators have started from the three possible bond types of the diketopiperazines with amino acids and peptides (I, II, III):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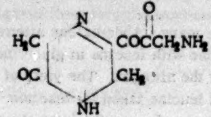
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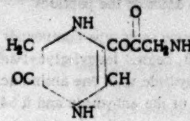
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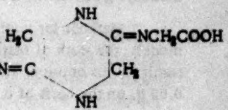
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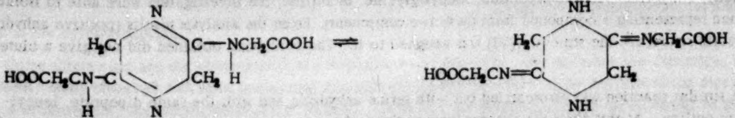
The first bond (I) is that made possible by the nitrogen of the diketopiperazine. Its possibilities were extensively studied by Abderhalden and co-workers [3]. Up to the present time this type of bond, although it has been considered the most probable by many authors, has not been experimentally proven. The second (II) and the third (III) types of bonds, which are derivatives of the two enol forms of the diketopiperazines, are under discussion, but likewise have not been experimentally realized. Many authors – Karrer, Abderhalden, Bergmann, and and others – have synthesized only the acyl and the alkylhydroxyl derivatives of the enolized diketopiperazines, and up to the present no one has described the introduction of aminoacyl groups. Because the diketopiperazines are quite inert substances, and because albumin is extremely labile, all the investigations therefore have been based principally upon the enol forms of diketopiperazine. In turn, not one of these forms has been proved. If attempts for their experimental realization have been made, they have not progressed farther than the point of hypothetical construction.

Lately, the authors have also demonstrated the possibility of a fourth type of bond [4] for the diketopiperazines with aminoacyl groups (IV). The reality of such a bond was proved by the synthesis of a new group of compounds – the aminoacyldihydropyrazines, capable of transforming into amidines as the result of desmotropic regrouping, i.e., to form immediately derivatives of piperazine and not of dihydropyrazine:



But the above-enumerated bonds and the new structural grouping proposed by the authors can hardly be considered as the only contributions to the structure of such a complex system as albumin. On the contrary, the diversity of albumin bodies, their properties and varied functions compel one to assume a diversity of amino acid conjugation forms.

In the present work we have concerned ourselves both with the synthesis of the corresponding N-acyl derivatives of diketopiperazine, and with their various reactions, considering to be possible the existence of such a bond, along with the amidinic form.

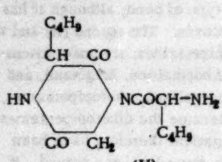
Many investigators have noted how difficult it is to hydrolyze dipeptides. In this respect diketopiperazine represents an even more inert substance than a dipeptide. It has been accepted that only the hydrogen on the nitrogen of diketopiperazine is very reactive. It is for this reason that the amide group has assumed the most dominant role in the search for the bond which connects diketopiperazines with amino acids.

In 1914 Maillard [5] obtained the first data on condensation between diketopiperazines and amino acids. By treating the amino acid mixture with a small quantity of glycerine, he isolated a mixture of substances which gave all of the typical reactions for albumin. It did not contain free amino acids, and upon this basis could be considered as consisting of diketopiperazine-amino acid derivatives. However, the individual substances were not isolated. Thus, Maillard first drew attention to the possibility of forming bonds between diketopiperazines and amino acids.

In 1925 Shibata upon heating albumin bodies in glycerine, obtained along with diketopiperazine, a substance which represented its derivative. It was not separated in its pure state, and therefore its structure was not determined.

Systematic work on the synthesis of diketopiperazines with side chains were carried out by Abderhalden and co-workers. However, Abderhalden went along a different line. Not aiming to find a bond between the individual diketopiperazines, he made an assumption concerning a bond between the latter and amino acids. According to Abderhalden, such a bond should be obtained by the aid of the diketopiperazine nitrogen and the carboxyl group of the amino acids or the peptides.

Methods for synthesizing such type compounds were many. Abderhalden attempting to decipher, with models, the work of Maillard, heated leucyl-glycyl-anhydride with leucine in glycerine, and obtained as the result, in his opinion, an anhydride with one amino acid at the nitrogen. The yield of substance obtained was 0.09 g, on the basis of 0.7 g of the anhydride and 0.54 g of leucine taken for reaction. The author does not mention qualitative reactions. According to analysis and molecular weight determination, the isolated compound coincided with leucyl-glycyl-leucyl anhydride. On the basis of analytical data only, the author made a decision on the structure of the compound, considering it to be the N-aminoacyl-derivative of leucyl-glycyl-anhydride (V):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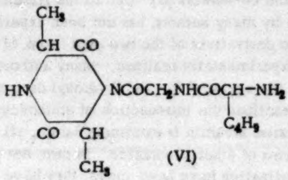

(VI)

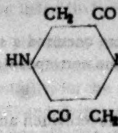
An analogous condensation was repeated with another amino acid – tyrosine. But in this case the heating of leucyl-glycyl-anhydride with tyrosine in glycerine did not lead to the individual compound. The substance obtained was characterized only by positive anhydride, ninhydrin and Millon reactions. The absence of analyses and yields make the author's assumption concerning the N-aminoacyl structure of this compound quite inconclusive.

In addition to heating in glycerine, condensation reactions were carried out in aniline. Upon boiling alanyl-alanyl-anhydride with the dipeptide, leucyl-glycine, in aniline, the investigators were able to isolate a substance representing a compound from these two components. From the analysis results (positive anhydride and ninhydrin reactions) the structure (VI) was assigned to it. The compound obtained did not give a biuret reaction.

A similar reaction was also carried out with serine anhydride and with the same dipeptide, leucyl-glycine, in aniline. At this time, the authors limited themselves to establishing only a ninhydrin reaction for the compound, pointing out at the same time the ability of the N-acyl bond to be split by pancreatin. The authors gave neither yield nor analysis nor properties other than theabsence of a biuret reaction. Consequently, the final structure of this compound was not determined.

The method of deriving the above compounds from the hydrochlorides of the tripeptide methyl esters gave considerably better results, in the opinion of Abderhalden. For this purpose, the latter were left at room temperature for several hours, and sometime for several days in an ammoniacal solution of methanol, depending upon the amino acids contained in the tripeptide. The precipitated crystals were filtered off and analyzed.

In this way there was obtained from the diglycyl-glycine ester, the glycyl-glycyl-glycyl anhydride (VII):



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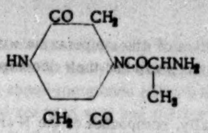
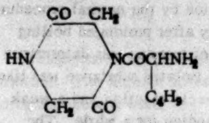


(VIII)

It was necessary to hold up on the analysis and purification of the substance. From the external appearance the precipitate from an ammoniacal methanol solution was found to be non-homogeneous, consisting of two substances. For their separation it was dialyzed, but the authors did not indicate by what they were guided in determining the completion of dialysis. The dialysate was then evaporated. The precipitate obtained gave a positive picrate reaction. The precipitate was found to be the diketopiperazine from the total nitrogen analysis. On the basis of the elementary analysis, the structure attributed to it was that of a diketopiperazine with a side chain. Inasmuch as the C, H and N content for the given compound is similar to that of diketopiperazine itself, then the essential proof for the structure attributed to the given compound would be the determination of amino nitrogen in it, which is just what the authors did not do.

By the same method alanyl-glycyl-glycyl-diketopiperazine (VIII) was obtained from the ester of alanyl-glycyl-glycine. Leucyl-glycyl-glycyl-anhydride (IX) was obtained from leucyl-glycyl-glycine. Leucyl-glycyl-seryl-anhydride (X) was obtained from leucyl-glycyl-serine:



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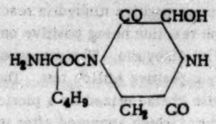
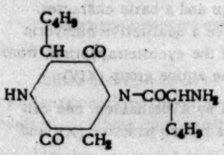


(X)

Leucyl-glycyl-tyrosyl-anhydride was obtained from leucyl-glycyl-tyrosine. It is regretted that the authentic structures for these compounds were not worked out completely.

Apart from the reactions with tripeptide esters, investigations were carried out with the free peptides. Thus, upon heating the tripeptide of leucyl-glycyl-leucine with 15 times the quantity of glycerine at 180-190° the authors observed anhydride formation without splitting off of the amino acid. The reaction product had the properties of substituted diketopiperazine (positive ninhydrin and anhydride reactions) and corresponded to the compound of structure (XI):



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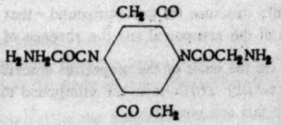


(XII)

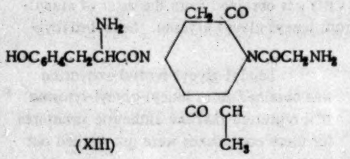
However, they did not quote any other proof for such a structure. As has been demonstrated later, a similar cyclization of the methyl esters of the tripeptides – diglycylglycine, alanyl-glycyl-glycine and leucyl-glycyl-glycine, carried out according to Abderhalden, leads not to diketopiperazine amino acid derivatives, but to the free diketopiperazines and amino acids or to the cylcotripeptide.

Quite interesting are the observations of Abderhalden and Schickel who obtained the dipeptide, alanyl-triptophane. They observed that, upon converting bromopropionyltryptophane into the corresponding dipeptide by means of ammonia, the anhydride is easily formed. A study of the properties of the latter points to its combination with the dipeptide. It is interesting that free amino groups were not found in the intermediate isovaleric compound, and that the anhydride failed to separate from the dipeptide. A spectrographic analysis of the substance has shown, in the course of an absorption curve, a great similarity with that from a mixture of the two components. On the basis of everything enumerated, the authors concluded that they were dealing with the N-aminoacyl compound of the anhydride.

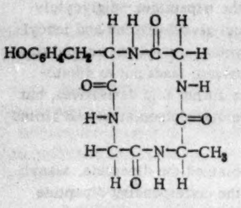
Apart from the reaction reviewed, Abderhalden utilized the amination reaction of dichloracyl derivatives of diketopiperazine with ammonia to prepare diketopiperazines bonded to amino acids. To do this, the authors synthesized a series of N-haloidacyl derivatives of diktopiperazine and in particulary N,N'-dichloracetyl-diketopiperazine. By amination of the latter, Abderhalden and Clarmann intended to obtain the 1,4-diglycyl-2,5-diketopiperazine (XII). In the following year they synthesized dibromisocaproyldiketopiperazine. Upon treating the substance obtained with alcoholic ammonia, the authors obtained the free diketopiperazine, which case doubt upon the correctness of the formula which they attributed to the substance obtained by amination of dichloracetyldiketopiperazine.

Thus, upon treating N-haloidacyl derivatives of diketopiperazine with ammonia, there occurred a simultaneous replacement of the halogen by the amino group and their decomposition to form the corresponding glycyl- or leucyl-amides and diketopiperazine.

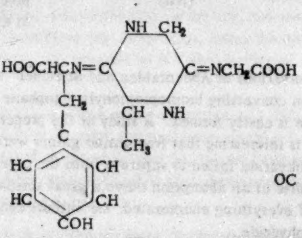
Apart from attempts to obtain, synthetically, compounds of the N-aminoacyl type, Abderhalden and his coworkers were concerned with explaining the structures of substances obtained by partial hydrolysis of albumins, and they were considered by them to be combinations of diketopiperazines with amino acids. Upon hydrolysis of silk and of casein, Abderhalden isolated such anhydrides which definitely contained the diketopiperazine ring. Molecular weight determination showed that they consisted of three or four amino acids. Such a complex ring could only be formed at the expense of amino acid bonds (tyrosine on the one hand and glycocol on the other) with the nitrogen of diketopiperazine (glycyl-alanyl-anhydride). Quite interesting is the complete characterization of this substance, obtained by treatment of silk fibroin with 70% H_2SO_4, on the basis of which Abderhalden arrived at the structure (XIII):

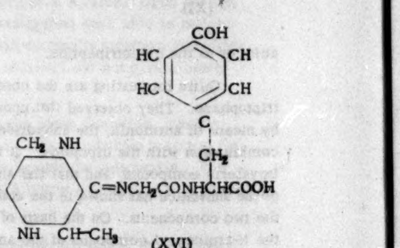

(XIII)

At first considering the isolated substance to be the tetrapeptide, tyrosyl-glycyl-alanyl-glycine, Abderhalden synthesized the analogous tetrapeptide and compared them with one another. The compounds isolated from silk did not give a positive ninhydrin reaction by the normal procedure, the reaction being positive only after prolonged boiling with ninhydrin. The presence of tyrosine was determined by a positive Millon test. The isolated substance was likewise characterized by a picric acid reaction and a weak biuret which appeared after standing for a while. The tetrapeptide obtained synthetically gave, on the other hand, a ninhydrin reaction but did not give a picric acid reaction. Abderhalden also studied the behavior of this substance with regard to 1 N alkali. The picric reaction disappeared if the isolated substance was heated with alkali or left standing for several hours at room temperature. At the same time a ninhydrin reaction appeared and an intensive biuret of red color. The latter attested to the breaking of the ring and the formation of a longer peptide chain. On the basis of these qualitative properties, only, Abderhalden arrived at the conclusion that the isolated substance was not identical with the tetrapeptide, but was instead the N,N'-diaminoacyl derivative of diketopiperazine. But, as follows from the formula attributed to it, this compound should have had free amine groups and a basic character. Abderhalden limited himself, however, only to the statement that this compound gave a qualitative ninhydrin reaction. He considered also another possible structure for this compound – that of the cyclotetrapeptide, from which clearly follows the neutral character of the compound and the absence of the amine group (XIV):


(XIV)

On the basis of the properties described by Abderhalden, one can hypothetically attribute to the compound the amidine structure (XV and (XVI) to this compound:


(XV)

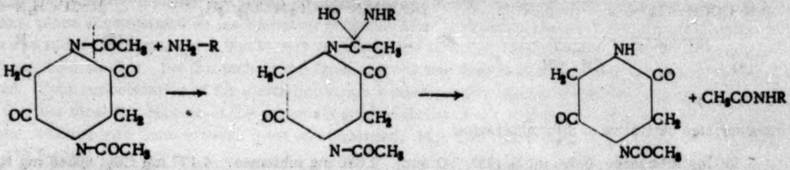

(XVI)

Thus, the multiple experiments carried out by Abderhalden with his co-workers on the synthesis of N-aminoacyl derivatives of diketopiperazines did not give satisfactory results. Numerous attempts to unite diketopiperazine with amino acids or with peptides by their direct interaction ended in failure.

In a majority of the cases characterization of the substances was limited only to analyses, and in some instances even they were not given, in which cases it can be definitely said that the authors were not dealing with the individual compound.

The above summary gives grounds for considering that Abderhalden's works on the N-aminoacyl type of bonding for the diketopiperazines is not sufficiently substantiated. Some interesting investigations bearing upon the possibility for the existence of the above-mentioned compounds in the free state were carried out by Bergmann [6] and Zehrwas. They obtained aceturic acid and the free diketopiperazine as the result of reaction of an alkaline solution of glycocoll with N,N'-diacetyldiketopiperazine.

This and the following observations led the authors to conclude that the bonding of diketopiperazine with amino acids by the nitrogen of the former should be unstable. Like diacetyldiketopiperazine, such compounds should be characterized by extreme lability toward ammonia and basic amino groups. From this point of view the negative experiments of Abderhalden and co-workers on the synthesis of N-diketopiperazine-amino acid derivatives can be explained by their ready cleavage and their difficulty of isolation:



Analogous reactions were explored in the works of Brunner [7] who utilized the acylamides for synthesis of amidines. The Brunner investigations gave an explanation to Bergmann's reacylation from the points of view stated in the present work.

Abderhalden's works found strong refutation in a series of articles, chiefly those of Bergmann and co-workers, and likewise in the investigations by one of us (N.I. Gavrilov) and Kh. N. Lerman [8], who demonstrated the impossibility of synthesizing N-aminoacyl-compounds by aminating N-haloidacyl diketopiperazines, and also by cyclizing tripeptide methyl esters. At the same time, the authors noted the formation of diketopiperazine in all cases.

No other attempts to unite diketopiperazines with amino acid or polypeptide groups through an amide bond are mentioned in the literature.

The above summary exhausts all of the information on synthesis of N-aminoacyl-derivatives of diketopiperazine.

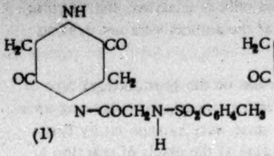
Since determination of the linkage between cyclic and the linear groupings is found to be essential for an explanation of the albumin structure, then the development of a synthetic method for making artificial models of such type compounds, and the study of their properties, is of utmost importance.

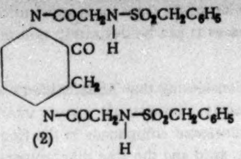
Having succeeded in demonstrating the amidine form of union and its likelihood in structural forms of albumin, we have drawn attention to the possibility of an N-aminoacyl combination of cyclopeptides with linear peptides. Having reviewed Abderhalden's failure to synthesize N-aminoacyl derivatives, in relation to the omission of the characteristic activity of the N-acyl compounds of diketopiperazines, the present authors nonetheless consider the synthesis of these compounds which may be present in the albumin structure, to be extremely important.

Direct aminoacylation of diketopiperazine was employed in approaching the problem of the synthesis of diketopiperazine with side chains. In the present work, the following N-aminoacylderivatives of diketopiperazine [1-6] were obtained: tolylsulfoglycyl-2,5-diketopiperazine [1], 1,4-dibenzylsulfoglycyl-2,5-diketopiperazine [2], 1,4-diphthalylglycyl-2,5-diketopiperazine [3], 1,4-diphthalylphenylalanyl-2,5-diketopiperazine [4], 1,4-diphthalylglycyl-glycyl-2,5-diketopiperazine [5] and N,N'-diformylglycyldiketopiperazine [6]: (see next page).

EXPERIMENTAL

1. Tolylsulfoglycyl-2,5-diketopiperazine [1]. 3.7 grams of tolylsulfoglycylchloride obtained by Fisher [9], diluted with 50 ml of nitrobenzene, was heated with 0.85 g of diketopiperazine for 2 hours at 140°. Absolute ether was added to the hot filtered solution. The precipitate was filtered off, washed with alcohol and ether. The substance obtained had a melting point of 220°. It gave a positive anhydride reaction. According to analysis it was


(1)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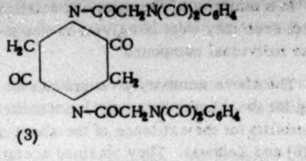
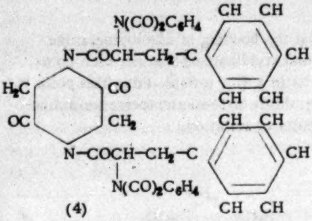
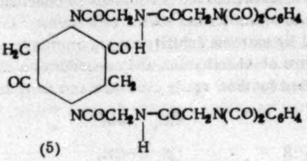

(3)


(4)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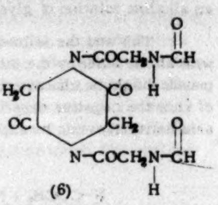

(6)

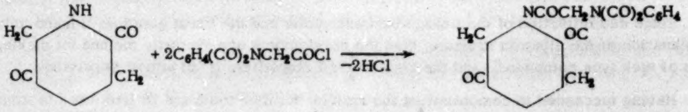
the monoacylated derivative of diketopiperazine.

6.760 mg substance: 0.793 ml N_2 (23°, 742 mm). 2.380 mg substance: 4.177 mg CO_2; 0.9548 mg H_2O. 3.156 mg substance: 5.536 mg CO_2; 1.289 mg H_2O. Found %: N 13.21; C 47.89, 47.87; H 4.49, 4.57. $C_{13}H_{15}O_5N_3S$. Calculated %: N 12.92; C 48.0; H 4.61.

2. 1,4-Dibenzylsulfoglycyl-2,5-diketopiperazine [2]. 1.3 g of benzylsulfoglycylchloride, obtained according to Johnson [10] was dissolved in 30 ml of nitrobenzene and heated with 0.3 g of diketopiperazine for 30 minutes at 140°. The hot solution filtered through a glass filter was precipitated by absolute ether. The precipitate which resulted upon standing was filtered and washed with alcohol. Recrystallized from nitrobenzene. Melting point of the substance obtained was 226° with decomposition. Positive anhydride reaction. According to analysis it was the diacylated derivative of diketopiperazine.

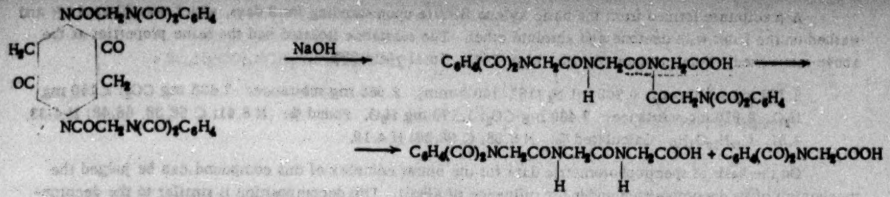
4.900 mg substance: 0.464 ml N_2 (23°, 737 mm). 3.005 mg substance: 5.455 mg CO_2; 1.170 mg H_2O. 3.105 mg substance: 5.625 mg CO_2; 1.250 mg H_2O. Found %: N 10.59; C 49.53, 49.45; H 4.36, 4.50. $C_{22}H_{24}O_8N_4S_2$. Calculated %: N 10.45; C 49.25; H 4.48.

3. 1,4-Diphthalylglycyl-2,5-diketopiperazine [3]. Reaction proceeded according to the scheme:


(3)

1.9 g of phthalylglycylchloride obtained according to [11] was ground in a mortar with 0.48 g of diketopiperazine. The mixture was placed in a Gavrilov apparatus and 25 ml of dry xylene was added. Heating was carried out in Wood's alloy at the boiling point of the solvent (146°) for 5 hours. After cessation of reaction, the precipitate was filtered off and washed on a filter with benzene (to remove unreacted phthalylglycylchloride due to solubility in benzene). The precipitate examined under the microscope contained diketopiperazine. Therefore all of the precipitate was treated twice with boiling water in a flask. The last wash waters did not contain diketopiperazine (negative picrate reaction). After washing with hot water, the precipitate was washed on the filter with alcohol. The melting point of the substance recrystallized from nitrobenzene was 385° with decomposition. Yield 83%. Partially soluble in boiling xylene and methyl acetate, likewise in acetone. Picric and ninhydrin reactions were negative; biuret – of the tripeptide type (upon standing with alkali).

3.570 mg substance: 0.382 ml N_2 (25°, 721.5 mm). 3.535 mg substance: 0.367 ml N_2 (23°, 726 mm). 3.375 mg substance: 7.290 mg CO_2; 1.00 mg H_2O. 3.218 mg substance: 6.949 mg CO_2; 0.9232 mg H_2O. Found %: N 11.48; C 59.01; H 3.28.



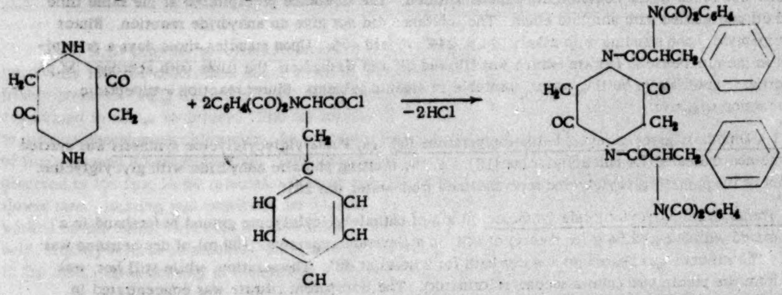
On the basis of spectrophotometry of the biuret reaction (maximum 590 mμ) the following decomposition of the substance in alkali can be assumed, which confirms the accepted structural formula above.

4. 1,4-Diphthalylphenylalanyl-2,5-diketopiperazine [4]. (a) Phthalyl-dl-phenyl-alanine synthesis [11], was carried out, with modification of the procedure used earlier. A mixture of 12.2 g of phthalic anhydride and 13.6 g of dl-phenylalanine was heated on an oil bath at 170-180° for 30 minutes. During this time solution took place accompanied by the formation of foam. After termination of reaction (transparent liquid) water was added to the mixture. Due to very poor solubility of phthalylphenylalanine in water, recrystallization was made from alcohol. For this purpose the fusion mixture was filtered from the water and dissolved in boiling alcohol. Upon concentration of the alcoholic filtrate a substance precipitated which was filtered off and washed with absolute alcohol. Because of the extremely good solubility of the substance in ether, and particularly in acetone, washing with these solvents is not recommended. M.p. 179°. According to the literature data [11], m.p. 177.5-179°.

(b) Phthalylphenylalanylchloride synthesis, was carried out in absolute benzene medium. A mixture of 2.36 g of phthalylphenylalanine and 1.67 g of PCl_5 was heated on a water bath at 60° with 10 times the weight of dry benzene. The mixture was shaken from time to time until a transparent solution resulted. About 30 minutes heating was needed for this. After cessation of reaction the solution was evaporated in vacuo, protected from the air moisture while heating. Upon concentration, the residue solidified immediately in the flask. Recrystallized from benzene + petroleum ether, m.p. 131°. Since the melting point of phthalylphenylalanylchloride (131°) obtained from benzene differed from the melting point of the chloranhydride of phthalylphenylalanine obtained from dioxane and described in the literature [11] (126°), the authors decided to analyze it.

6.010 mg substance: 0.235 ml N_2 (19°, 737 mm). Found %: N 4.42. $C_{17}H_{12}O_3NCl$. Calculated %: N 4.46.

(c) Synthesis of diphthalylphenylalanyl-2,5-diketopiperazine in dry xylene medium. The reaction proceeds according to the following scheme:

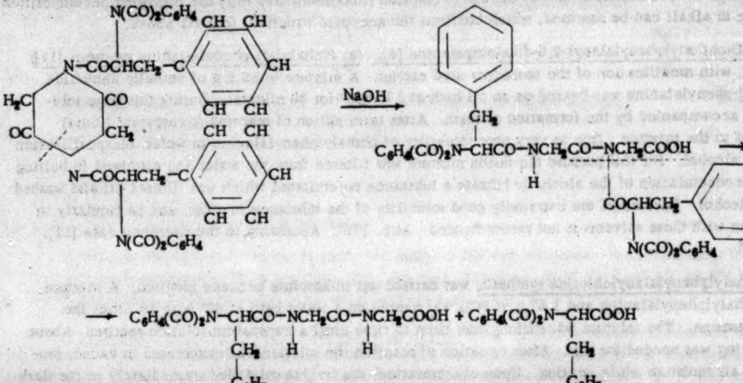


0.55 g of diketopiperazine was ground in a mortar with 3.15 g of phthalylphenylalanylchloride. The mixture was placed in a flask with a reflux condenser and 40 ml of dry xylene was added. Heating was carried out in a Wood's alloy bath for 6 hours at the boiling point (160° in the alloy). After 30 minutes everything was dissolved. Reaction continued for another 5 hours and 30 minutes. Upon termination the solution was cooled. The resulting precipitate was filtered off and washed with acetone. From the acetone filtrate a substance was isolated by precipitation with absolute ether, composed of well-defined rods, as seen under the microscope. M.p. 210°, not soluble in anything. Anhydride reaction was negative, biuret — tripeptidic upon standing with alkali. Maximum absorption at 590 mμ. Total nitrogen 7.81%.

A precipitate formed from the basic xylene filtrate upon standing for 3 days, which was filtered off and washed on the filter with acetone and absolute ether. The substance isolated had the same properties as the above-mentioned. Total nitrogen 8.41%. M.p. 244°. Total yield 75%.

2.795 mg substance: 0.206 ml N_2 (18°, 740.5 mm). 2.965 mg substance: 7.435 mg CO_2; 1.150 mg H_2O. 2.970 mg substance: 7.460 mg CO_2; 1.170 mg H_2O. Found %: N 8.41; C 68.38, 68.48; H 4.33, 4.31. $C_{38}H_{28}O_8N_4$. Calculated %: N 8.38; C 68.26; H 4.19.

On the basis of spectrophotometric data for the biuret complex of this compound can be judged the mechanism of its decomposition under the influence of alkali. This decomposition is similar to the decomposition of the earlier-described 1,4-diphthalylglycyl-2,5-diketopiperazine.



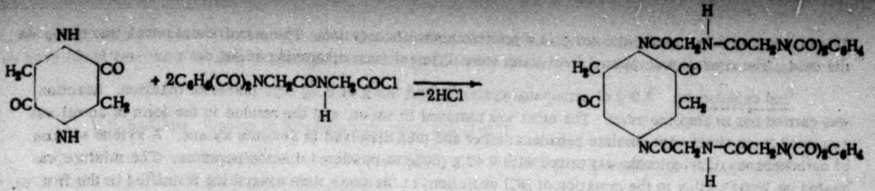
(d) Synthesis of 1,4-diphthalylphenylalanyl-2,5-diketopiperazine in nitrobenzene. 0.55 g of finely-powdered diketopiperazine was mixed with 3.15 g of phthalylphenylalanylchloride. The mixture was placed in a three-necked flask equipped with a reflux condenser and stirrer. 40 ml of nitrobenzene was added to the mixture and the mixture was heated in Wood's alloy at 160°; within thirty minutes everything was dissolved. Upon heating for an additional hour, the solution began to resinify, which forced termination of the reaction. Absolute ether was added to the cooled nitrobenzene solution. The substance precipitated at the same time was filtered off and washed with absolute ether. The substance did not give an anhydride reaction. Biuret reaction – tripeptide, upon standing with alkali. M.p. 244°. Yield 45%. Upon standing three days, a precipitate formed in the nitrobenzene filtrate, which was filtered off and washed on the filter with acetone. M.p. 245°. Properties: insoluble in boiling water, insoluble in organic solvents. Biuret reaction – tripeptidic. Anhydride reaction negative.

5. 1,4-Diphthalylglycylglycyl-2,5-diketopiperazine [5]. (a) Phthalylglycylglycine synthesis was carried out by the method indicated for phthalylglycine [12], i e., by melting phthalic anhydride with glycylglycine. Melting point of the phthalyl glycylglycine recrystallized from water was 231°.

(b) Phthalylglycylglycylchloride synthesis. 3.2 g of phthalylglycylglycine ground beforehand in a mortar was mixed with 3.2 g (2.54 g for theory) of PCl_5 in a Gavrilov apparatus. 100 ml of dry benzene was then added. The mixture was heated on a water bath for 2 hours at 80°. The solution, while still hot, was filtered off from the precipitate (into a second chlorinator). The transparent filtrate was concentrated in vacuo to a small volume by heating. The precipitate formed was filtered off and washed with absolute ether. M.p. 128° with decomposition.

6,900 mg substance: 0.612 ml N_2 (25°, 749 mm). Found %: N 10.02. $C_{12}H_9O_4N_2Cl$. Calculated %: N 9.98.

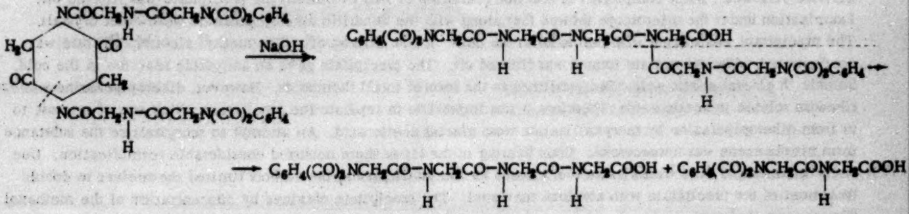
(c) 1,4-Diphthalylglycylglycyl-2,5-diketopiperazine synthesis.
1 g of phthalylglycylglycylchloride was dissolved in 10 ml of nitrobenzene (very readily soluble). The solu-



tion was placed in a three-necked flask equipped with mechanical stirrer, wherein 0.2 g of finely-powdered diketopiperazine had been previously powdered. The mixture was heated in Wood's alloy at 140° for one-hour. Heating was accompanied by coloration. After completion of reaction the solution was cooled and filtered from the precipitate, which was found to be diketopiperazine. The filtrate was precipitated with absolute ether. The resulting precipitate was filtered off and washed on the filter with methyl acetate. The resulting precipitate was absolutely insoluble in boiling water as well as in organic solvents. It gave a strong anhydride reaction upon gentle heating. The biuret reaction was of the tetrapeptide type (upon standing with alkali). M.p. above 340°.

3.490 mg substance: 0.435 ml N_2 (22°, 743 mm). 5.591 mg substance: 0.530 ml N_2 (24°, 745 mm). 2.415 mg substance: 5.945 mg CO_2; 0.7724 mg H_2O. 3.170 mg substance: 6.275 mg CO_2; 0.9831 mg H_2O. Found %: N 14.09, 13.98; C 55.83, 55.98; H 3.58, 3.47. $C_{28}H_{22}O_{10}N_6$. Calculated %: N 13.95; C 55.81; H 3.65.

On the basis of spectrophotometric data for the biuret complex, an idea about the manner of disintegration of this substance under the influence of alkali can be drawn up. This disintegration was confirmed by the presence of two maxima at 535 mμ and at 620 mμ, and is analogous to the decomposition of 1,4-diphthalylglycyl-2,5-diketopiperazine, as can be presented by the following scheme:



6. N,N'-Diformylglycyldiketopiperazine synthesis [6]. 0.5 g of finely-powdered formylglycine [13] was introduced into the chlorinator and 3.12 ml of freshly-distilled acetyl chloride and 1.06 g of finely-powdered and freshly-prepared PCl_5 was added. All of the formylglycine dissolved upon shaking and cooling. The solution was evaporated in vacuo to dryness. The dry residue in the chlorinator was treated three times with dry petroleum ether to remove phosphorous chloroxide. 30 ml of dry benzene was added to the precipitate in the chlorinator plus 0.2 g of finely-ground diketopiperazine. Upon heating on a water bath at 60° vigorous evolution of hydrogen chloride was observed in the first 15-20 minutes. Heating was continued at 70°. Evolution of hydrogen chloride proceeded at a slower rate. Heating was continued for 5 hours. After completion of reaction, the precipitate was filtered off and washed on the filter, first with dry acetone and then with ether. The substance obtained was soluble in formic acid, slightly soluble in alcohols, ethyl and methyl acetates, and in water. It gave a vigorous anhydride reaction in the cold. Upon heating in a capillary, it decomposed at about 200° with intense darkening.

0.0702 g substance: 8.86 ml 0.1 N NaOH (corresponding to 8.86 ml 0.1 N H_2SO_4). Found %: N 20.20. $C_{10}H_{12}O_6N_4$. Calculated %: N 19.7.

Due to the very poor yield of substance in the second stage of the synthesis, the preparation of formylglycylchloride was abandoned

7. N,N'-Dicarbobenzoxyalanyldiketopiperazine synthesis. (a) Condensation reaction in xylene. 1st experiment: 0.25 g of finely-ground diketopiperazine was mixed with 1.3 g of carbobenzoxyalanylchloride in 10 ml of dry xylene. It was heated in Wood's alloy for 10 minutes at 120°. HCl was evolved. After cessation of reaction the precipitate was filtered off and washed with absolute ether. The substance obtained

did not contain chlorine, and did not give a positive ninhydrin reaction. The anhydride reaction was strong in the cold. The crystals precipitated from water were different from diketopiperazine.

2nd experiment: 3.3 g of carbobenzoxyalanine and 3.5 g of PCl_5 were taken for reaction. Reaction was carried out in absolute ether. The ether was removed in vacuo, and the residue in the form of an oil was extracted three times with absolute petroleum ether and then dissolved in absolute xylene. A xylene solution of carbobenzoxyalanylchloride was mixed with 0.42 g (50%) of powdered diketopiperazine. The mixture was heated on Wood's alloy to the cessation of HCl evolution; at the same time everything resinified in the first 15 minutes. The precipitate was then filtered off and treated on the filter with methanol and water in the cold. A portion dissolved. The undissolved portion represented diketopiperazine. A drop of the aqueous filtrate under the microscope represented a mixture of the diketopiperazine and of a new substance (small rhomboids).

It was observed that upon condensing carbobenzoxyalanylchloride with diketopiperazine in xylene there occurred strong resinification, even upon heating on the water bath. It was therefore necessary to substitute another solvent for xylene. Reactions were carried out in absolute benzene and in ether media. The most interesting results were obtained upon conducting the reaction in absolute ether.

(b) Condensation reaction in ether. 3rd experiment. 2.2 g of carbobenzoxyalanine and 2.1 g of PCl_5 were taken for reaction. The reaction was carried out in absolute ether medium. After completion, the ether was distilled off in vacuo and the oil, treated three times with petroleum ether, was dissolved in absolute ether and used for the condensation reaction with diketopiperazine.

Upon heating carbobenzoxyalanylchloride with 0.25 g of diketopiperazine in absolute ether, HCl did not evolve in the first 10 minutes. After a half hour of boiling, the precipitate was examined under the microscope. From water it had the form of diketopiperazine. The precipitate did not change externally during the time of reaction in ether. Then, having removed the ether from the reaction flask by simple heating with the condenser disconnected, xylene was added to the flask and heated. Upon heating, HCl evolution was observed and the precipitate yellowed. After completion of reaction (cessation of HCl evolution) the precipitate was filtered off. Examination under the microscope showed that, along with the dendritic diketopiperazine were other crystals. The precipitate was treated with methanol in the cold It was filtered off. The methyl alcoholic filtrate was concentrated. The precipitate formed was filtered off. The precipitate gave an anhydride reaction in the cold. Soluble in glacial acetic acid. Recrystallized in the form of small rhomboids. However, diketopiperazine was likewise soluble in acetic acid. Therefore it was impossible to separate the precipitate which was of interest to us from diketopiperazine by recrystallization from glacial acetic acid. An attempt to recrystallize the substance from nitrobenzene was unsuccessful. Upon heating in the latter there occurred considerable resinification. Due to the enumerated difficulties (choice of solvent for recrystallization) the authors limited themselves to double treatment of the precipitate with absolute methanol. The precipitate obtained by concentration of the methanol filtrates was analyzed.

7.195 mg substance: 0.706 ml N_2 (20°, 738 mm). 6.320 mg substance: 0.501 ml N_2 (25°, 736 mm). Found %: N 11.85, 11.81. $C_{26}H_{28}O_8N_4$. Calculated %: N 10.69.

According to the nitrogen content, the substance was contaminated with 10% of diketopiperazine. The difficulty in separating the resulting substance from diketopiperazine prevented the use of this method for derivation of N-aminoacyldiketopiperazine.

SUMMARY

Starting from the above-quoted literature review it follows that the problem of N-acylated diketopiperazines appears to be a most interesting and important problem, both in synthesis and in albumin transformation.

The impossibility of the N-aminoacyldiketopiperazine synthesis route chosen by Abderhalden was demonstrated by the work of Bergmann and the authors. Therefore, up to our time, no one has succeeded in obtaining N-aminoacyl derivatives of diketopiperazines.

Upon reviewing the unsuccessful attempts of Abderhalden to derive such type compounds, conditioned chiefly by the great reactivity of the N-acyl derivatives of diketopiperazine, the authors believe that their synthesis is extremely important. Starting from the ease of acylation of diketopiperazines by chloranhydrides of acids, the authors have obtained the following N-aminoacyl derivatives of diketopiperazine: (1,4) N,N'-dibenzylsulfo-, (1,4) N,N'-ditolylsulfo-, (1,4) N,N'-diphthalylsulfo, (1,4) N,N'-diformylglycyl- and (1,4) N,N'-

diphthalylglycylglycyl-2,5-diketopiperazines. Upon investigating further the transformations of these compounds, we have found that their lability is generally characteristic for all N-acyl derivatives of diketopiperazine.

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THE STRUCTURE OF ALBUMIN

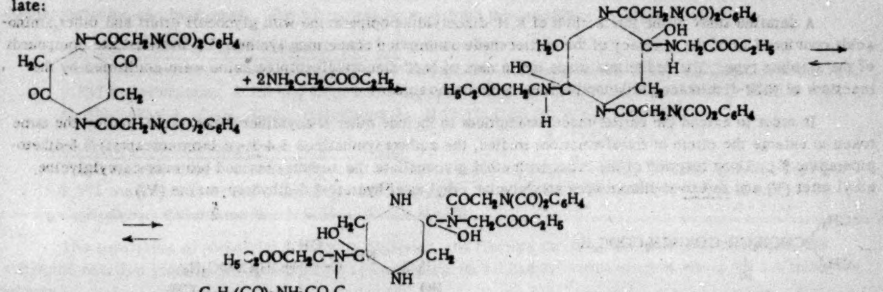
XI. SOME REACTIONS OF DIACYLDIKETOPIPERAZINES

L. N. Akimova and N. I. Gavrilov

In the preceding article [1], the authors have demonstrated the ease of acylation of diketopiperazine by amino acid chloranhydrides with protected amino groups. There resulted nitrogen substituted diketopiperazines (N,N'-diaminoacyldiketopiperazines). The synthesis of phthalyl derivatives of amino acids were of most interest. Their chloranhydrides were especially easy to condense with diketopiperazine to form N,N'-diphthalylaminoacyldiketopiperazines.

Upon reacting phthalylglycylchloride with diketopiperazine, an almost quantitative yield of 1,4-diphthalylglycyl-2,5-diketopiperazine was formed. This complex N-aminoacyl-derivative of diketopiperazine behaves in exactly the same manner as the other(simpler) N-acyl derivatives of diketopiperazine, as has been demonstrated in the present work.

Using the addition reaction of the amino group of amino acids to the carbonyl group of N-acylsubstituted diketopiperazines [2], discovered by the authors, they have obtained di-exo-N-phthalylglycylglycine ethyl ester hydrate-2,5-dihydropyrazine (I), by interaction of 1,4-diphthalylglycyl-2,5-diketopiperazine with ethyl glycocollate:

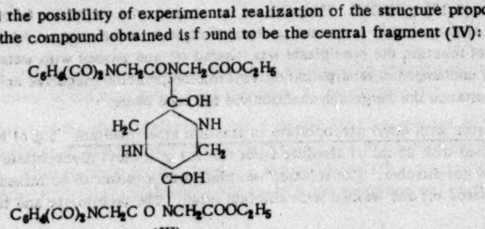

N–COCH₂N(CO)₂C₆H₄
H₂C
CO
OC
CH₂
N–COCH₂N(CO)₂C₆H₄
+ 2NH₂CH₂COOC₂H₅
N–COCH₂N(CO)₂C₆H₄
OH
H₂O
C–NCH₂COOC₂H₅
HO
H
H₅C₂OOCH₂CN–C
CH₂
H
N–COCH₂N(CO)₂C₆H₄
NH
COCH₂N(CO)₂C₆H₄
H₂C
HO
C–N–CH₂COOC₂H₅
OH
H₅C₂OOCH₂C–N–C
CH₂
NH
C₆H₄(CO)₂NH₂CO C

(I)

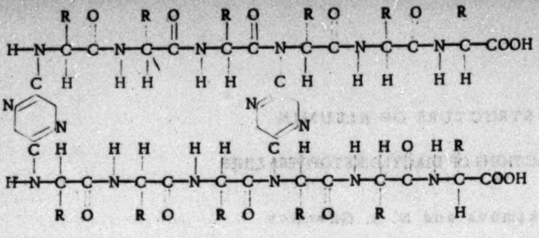
In addition to this compound, which was found to be the amidine derivative of diketopiperazine and phthalyldipeptide(glycylglycine), the acylated ethyl glycocollate was obtained. In this case the acyl group was phthalyl-glycine, which led to the formation of the phthalylglycylglycylic ester $C_6H_4(CO)_2NCH_2CONHCH_2COOC_2H_5$ (II).

As for the simplest N-acyldiketopiperazines, the endo-acyl group (phthalylglycyl-) was likewise regrouped to the exo-position and compound (III) was formed.

This synthesis confirmed the possibility of experimental realization of the structure proposed in 1947 by one of us (N.I. Gavrilov), since the compound obtained is found to be the central fragment (IV):


C₆H₄(CO)₂NCH₂CONCH₂COOC₂H₅
C–OH
H₂C
NH
HN
CH₂
C–OH
C₆H₄(CO)₂NCH₂C O NCH₂COOC₂H₅

(III)



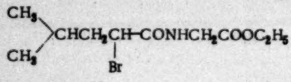
(IV)

In the carrying out of numerous investigations for the purpose of explaining the albumin structure and the possible binding of diketopiperazines with amino acids by nitrogen, Abderhalden and his co-workers used the amination reaction of dichloracyl derivatives of diketopiperazine by ammonia. Considering combinations of diketopiperazines with acyl halides to be the preliminary step for synthesis of N-aminoacyl derivatives of diketopiperazine, the authors synthesized a series of N-haloidacyl derivatives of diketopiperazine: N,N'-dichloracetyldiketopiperazine; N,N'-α-dibromisocapryldiketopiperazine. Upon treatment of the above-enumerated compounds with ammonia, their decomposition was observed, with the formation of the amides of the amino acids and the diketopiperazine.

In one of our articles, the reactivity of N-acylated diketopiperazines was clearly demonstrated in the examples of N,N'-diacetyl- and N,N'-dichloracetyl-diketopiperazines. Their extraordinary lability was established with regard to the free amino groups and their ability to enter into reactions with bases, forming at the same time acylated amidines.

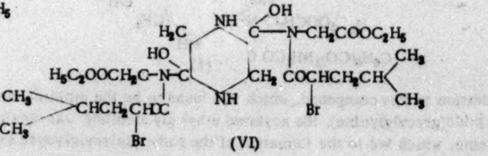
A detailed study of the interactions of N,N'-diacetyldiketopiperazine with glycocoll esters and other amino-acids, convinced us of the accuracy of the earlier-made assumption concerning synthesis of intermediate compounds of the amidine type. The deductions made in the case of N,N'-diacetyldiketopiperazine were confirmed by the reactions of N,N'-dichloracetyldiketopiperazine with amino acids.

In order to extend the earlier-made assumptions to include other N-acyldiketopiperazines, and by the same token to enlarge the circle of transformations studied, the authors synthesized 1,4-di-(α-bromnorcapryl)-2,5-diketopiperazine [3]. Upon reaction of the latter with ethyl glycocollate, the authors obtained bromnor-caprylglycine ethyl ester (V) and di-exo-N-dibrom-nor-caprylglycine ethyl ester hydrate-2,5-dihydropyrazine (VI).



$(CH_3)_2CHCH_2CH(Br)CONHCH_2COOC_2H_5$

(V)



(VI)

EXPERIMENTAL

1. Condensation Reaction of N,N'-Diphthalylglycyldiketopiperazine with Glycocoll. a) Conjugation with glycocoll in water. 1 g of N,N'-diphthalylglycyldiketopiperazine was mixed with 0.31 g of glycocoll (2 moles) in alkaline solution (0.165 g NaOH). The solution was shaken on a rocker for 5 hours; no change occurred during this time. A drop of the solution contained unchanged crystals of the original substance under the microscope. After termination of reaction, the precipitate was filtered off and washed with water. The remaining precipitate (0.9 g) represented unchanged N,N'-diphthalylglycyldiketopiperazine (negative anhydride and ninhydrin reactions). Therefore in this instance the Bergmann reaction did not take place.

b) Conjugation with ethyl glycocollate in absolute ether medium. 5 g of N,N'-diphthalylglycyldiketopiperazine was mixed with 25 ml of absolute ether and 2.1 g of ethyl glycocollate in 25 ml of absolute ether. The precipitate did not dissolve. The solution was placed on a rocker to be mixed. After 7 days of reaction, the precipitate was filtered off and washed with absolute ether. The precipitate and filtrate were examined separately.

Into the ether filtrate, basic in reaction, was passed dry hydrogen chloride. The precipitate formed was filtered off and washed with ether. The weight of dried substance was 0.8 g. By analysis, the substance was found to be ethyl glycocollate hydrochloride (m.p. 145°, NH_2=10.04%).

The precipitate was treated with chloroform. The chloroform filtrate was concentrated in vacuo in the cold. The separated precipitate was filtered off and washed with absolute ether. The substance obtained dissolved readily in chloroform and in acetone. It was precipitated from chloroform by ether. M.p. 160°. Weight 1.65 g.

Purification of the substance. The precipitate was dissolved in hot water and filtered while hot. Upon standing at room temperature, a precipitate separated from the aqueous solution, which was filtered off and washed on the filter with water, alcohol and ether (it was soluble in the last two). Since the precipitate was not homogeneous under the microscope, it was treated again with methyl acetate. A small portion dissolved (needles), but the greater portion did not go into solution (flakes) when a sample was checked under the microscope. The filtrate was concentrated to a small volume, and a substance with m.p. 183° was separated from it. The precipitate did not dissolve in methyl acetate; it melted at 145°.

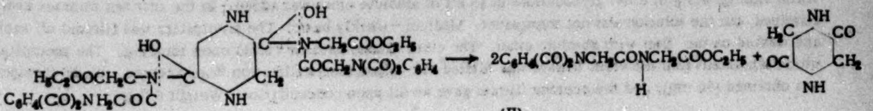
The aqueous filtrate and the mother liquor from the recrystallization was concentrated by heat in vacuo. Upon treating with methyl acetate, two substances were separated with melting points as indicated above. The compound with m.p. 183° was analogous in its properties to the above-described, as was the compound with m.p. 145°

The precipitate weighed 4.3 g after treatment with chloroform. This precipitate gave a picric reaction and a biuret of the tripeptide type upon standing with alkali. It was treated three times in a beaker with hot water. It was filtered off and washed on the filter with boiling water and alcohol. The precipitate now did not give an anhydride reaction, and the biuret reaction was, as before, of the tripeptide type. Therefore, by the appearance of the anhydride reaction for the isolated substance up to the point of treatment of the precipitate with hot water, and by its disappearance after treatment of the precipitate with hot water, the presence in the precipitate of free diketopiperazine can be judged. The substances isolated from this reaction were analyzed.

Analysis of the substance with m.p. 145° (I).
2.465 mg substance: 0.264 ml N_2 (25°, 734.4 mm). 3.015 mg substance: 5.185 mg CO_2; 1.296 mg H_2O.
3.027 mg substance: 6.130 mg CO_2; 1.294 mg H_2O. Found %: N 11.84; C 55.10, 55.27; H 4.95, 4.86.
M 678.7 (Rast.). $C_{32}H_{34}O_{12}N_6$. Calculated %: N 12.11; C 55.33; H 4.899; M 694.

Analysis of the substance with m.p. 183° (II).
3.005 mg substance: 0.260 ml N_2 (19°, 734 mm). 2.960 mg substance: 6.276 mg CO_2; 1.293 mg H_2O.
2.975 mg substance: 6.310 mg CO_2; 1.292 mg H_2O. Found %: N 9.76; C 57.86, 57.88; H 4.89, 4.86.
$C_{14}H_{14}O_5N_2$. Calculated %: N 9.65; C 57.93; H 4.83.

The separation of phthalylglycylglycine ethylester, and likewise the tracing of diketopiperazine by the anhydride reaction indicate a decomposition characteristic for all hydrate forms of amidines as per the following scheme:

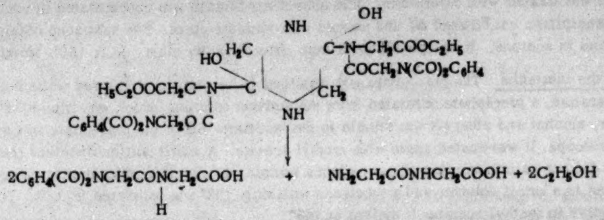


(II)

(I)

Moreover, the presence of phthalylglycylglycine ethyl ester in the reaction products points to the fact that there also takes place a rearrangement of the acyl group from the endo- to the exo-position.

As proof of the rearrangement of the phthalylglycine group from the nitrogen position in the piperazine ring to the nitrogen of the side amino acid, arrangement was made to hydrolyze this compound with 1% hydrochloric acid with and without an enzyme. After standing for two days in a thermostatic bath, a precipitate separated from both solutions, which was found to be phthalylglycylglycine. For analysis the substance was recrystallized from water. M.p. 229.5°. The complete absence of the anhydride and the biuret reactions, carried out with both $CuCl_2$ and $Co(NO_3)_2$, indicated that the substance isolated by the authors represented phthalylglycylglycine. The synthetic phthalylglycylglycine melted at 230° and did not give depression with the above-isolated substance. The decomposition scheme of the amidine in 1% HCl is cited below.



Diketopiperazine was not found. Its presence in this compound was demonstrated by the appearance in the filtrate of a ninhydrin reaction and a biuret of the dipeptide type. This experiment confirmed the assumption made earlier regarding the location of the phthalylglycine group on the nitrogen of the side chain.

2. Synthesis of 1,4-di-(α-bromnorcapryl)-2,5-diketopiperazine. 2 g of diketopiperazine was mixed with 11 g of α-brom-nor-caprylchloride [4]. Xylene (35 ml) was then added as the solvent and a few drops of thionyl chloride to speed the reaction. The mixture was heated on reflux in Wood's alloy at 138°. After 5-6 hours of boiling the strongly colored solution was filtered through a glass filter while still hot. The filtrate obtained was concentrated by heating in vacuo to an oily residue. To this residue in the flask was then added 100 ml of absolute ether. Upon prolonged standing (2-3 hours) in a cooling mixture a white crystalline powder precipitated, which was filtered off and washed with absolute ether. The substance was recrystallized from alcohol for analysis. M.p. 118°. Yield 4.5 g (instead of the theoretical 8.11 g).

In order to cut down on resinification, the experiments were carried out in benzene and toluene.

It is better to carry out the reaction with a stirrer. It was not possible to obtain 1,4-di-(α-brom-nor-capryl)-2,5-diketopiperazine in either the first or the second solvent.

It was observed that optimum conditions are: solvent – dry xylene, absence of thionyl chloride and preliminary stirring of the solution to avoid burning of the diketopiperazine which lies on the bottom of the flask.

8.500 mg substance: 0.481 ml N_2 (25°, 751 mm). 3.168 mg substance: 4.751 mg CO_2; 1.310 mg H_2O.
3.206 mg substance: 4.812 mg CO_2; 1.310 mg H_2O. Found %: N 6.04; C 40.93, 40.97; H 5.25, 5.21.
$C_{16}H_{24}O_4N_2Br_2$. Calculated %: N 5.98; C 41.03; H 5.17.

3. Condensation of 1,4-di-(α-brom-nor-capryl)-2,5-diketopiperazine with Ethyl Glycocollate in Absolute Ether Medium. 1.1 g of dibrom-nor-capryldiketopiperazine was placed in a flask and 10 ml of absolute ether added. While stirring, 0.5 g of ethyl glycocollate in 10 ml of absolute ether was added. In the first ten minutes everything dissolved, but the solution was not transparent. Medium – weakly basic. The precipitate was filtered off rapidly and washed on the filter with absolute ether. The ether filtrate became turbid upon standing. The precipitate which separated from the ether filtrate was filtered off. Upon recrystallization from acetone, the diketopiperazine was obtained (50 mg), and the acetone filtrate gave an oil upon concentration. Weight 0.7 g.

Treatment of the ether filtrate. The ether filtrate was concentrated in vacuo in the cold to an oily residue which crystallized instantly. The separated substance was dissolved in a very small volume of benzene with heating, was cooled and precipitated by petroleum ether. The separated precipitate was filtered off and washed on the filter with petroleum ether. The dry precipitate weighed 0.6 g. Upon analysis, the precipitate was found to be the brom-nor-caprylglycine ethyl ester. M.p. 78°.

8.970 mg substance: 0.513 ml N_2 (24°, 751 mm). 3.055 mg substance: 4.816 mg CO_2; 1.800 mg H_2O.
3.050 mg substance: 4.800 mg CO_2; 1.800 mg H_2O. Found %: N 4.92; C 43.01, 42.94; H 6.59, 6.60.
$C_{10}H_{18}O_3NBr$. Calculated %: N 5.0; C 42.86; H 6.43.

The precipitate from the ether filtrate was recrystallized from water. Melting point of the dried substance was 120°, soluble in methanol, chloroform, very readily in acetone, insoluble in water.

2.795 mg substance: 0.206 ml N_2 (18°, 740.5 mm). 3.020 mg substance: 4.719 mg CO_2; 1.325 mg H_2O. 3.160 mg substance: 4.932 mg CO_2; 1.330 mg H_2O. Found %: N 8.41; C 42.64, 42.59; H 6.20, 6.16. $C_{24}H_{42}O_8N_4Br_2$. Calculated %: N 8.31; C 42.73; H 6.23.

SUMMARY

1. Di-exo-N-phthalylglycylglycine ethyl ester hydrate-2,5-dihydropyrazine amidine was obtained.

2. Di-exo-N-brom-nor-caprylglycine ethyl ester hydrate-2,5-dihydropyrazine was obtained.

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SPECTROPHOTOMETRY OF BIURET COMPLEXES AS A METHOD FOR THE INVESTIGATION OF ALBUMINS AND PEPTIDES

XV. APPLICATION OF THE BIURET REACTION WITH NICKEL TO THE INVESTIGATION OF GELATIN HYDROLYSIS

M. I. Plekhan and E. N. Voluiskaya

Hydrolytic break-down of albumin substances and the investigation of their decomposition products is one o the first methods in attempting to understand the structure o albumin substances.

If the separation of individual compounds from albumin hydrolyzates offers difficulties, it is more difficult to determine through what phases disintegration of the albumin molecule passes. Up to the present time, chemical characterization of the process as a whole has been based principally upon change in nitrogen combinations. Attempts have been made to observe disintegration of the molecule with the help of the ultracentrifuge, by decrease in the molecular weight of the fragments. With regard to complete characterization of the overall variety of substances forming during the different phases of disintegration of albumin, the picture at the present is obscured if the final hydrolytic phases are not considered where reactions lead to a mixture of amino acids. It is apparent that each new method of investigation should be applied, and the reactions, to a partial if not complete clarification of this complex field.

Taking into account the considerations stated, we have utilized certain observations made upon nickel biuret complexes of the peptides, which were obtained earlier by the authors [1] in order to investigate gelatin hydrolysis under various conditions. Against the background of the tripeptide orange complex, and the yellow complexes of the peptides, with a longer chain, the nickel complex of the dipeptide differs markedly, not only in its blue color, but also in its absorption curve maximum.

During the process of albumin disintegration it could be expected that the appearance of dipeptide and amino acid complexes should be accompanied by a characteristic change in color, and by a corresponding change in the absorption curve. The color of the albumin complex should change from orange to green and the absorption curve should exhibit a maximum at wave length ~ 630 mμ. Speaking to the point, it has not been known up to the present time at which stage of disintegration dipeptides and amino acids appear. In our investigations we have endeavored to answer this question in the case of enzymatic acid and basic hydrolysis of gelatin. Before going into the direct investigation of albumin hydrolyzates, it was necessary to complete certain preliminary experiments: 1) quantitative determination of nickel in peptide complexes; 2) determination of how the absorption character of the nickel biuret complex of one peptide is changed if in the solution there appears the complex of a peptide of different chain length.

1. The Nickel Content of Biuret Complexes for Peptides.

Electrolytic determinations of nickel in peptide complexes led to the results cited in Table 1.

The colorimetric method [2] for determining nickel gave values close to those cited in Table 1, and can be substituted for the electrolytic method. In further experiments on hydrolyzate complexes, the authors have applied the colorimetric method for determining nickel. Results cited in Table 1 indicate that the nickel content is highest in the tripeptide orange complex.

Regarding the structure of the nickel biuret complexes of the peptides, the following can be said for the time being:

1) Upon subjecting the nickel complexes of peptides and albumins to the action of an electric current, the authors have observed that they are shifted toward the anode. Consequently, the colored portion of the complex belongs to anionic nickel and the organic portion of the complex is contained in the anion. Evidently the nickel biuret complexes of the peptides belong to the same group of higher complex compounds as the copper complexes. At present it is not clear just what coordination number nickel has in these complexes.

TABLE 1

Name of substance	Quantity of substance (in mg/1 mg nickel)	Number of moles of substance per g-atom Ni	Number of of g-atoms of total nitrogen per g-atom Ni
Glycylglycine	7.34	3.58	7.16
Diglycylglycine	4.1	1.26	3.78
Triglycylglycine	6.87	1.32	5.28
Alanine	60	40	40

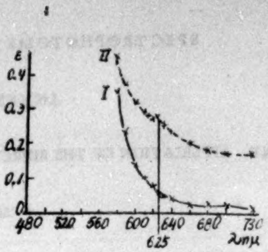


Fig. 1.

2) In a series of complex peptides the most perfect is found to be the yellow biuret complex which is formed by the tetrapeptide and by peptides with a longer chain. The tetrapeptide is able to replace tripeptide and dipeptide from the nickel biuret complex. A tripeptide is only partially able to replace a dipeptide from its nickel biuret complex, which indicates the rather close similarity in activity in formation of tri- and di-peptides complexes.

2. Formation of nickel biuret complex in an environment of glycyl peptide mixtures.

In experiments with glycylic di-, tri- and tetra-peptides was determined the manner in which the absorption character changes if in a solution of one of the complexes there appears the complex of another peptide.

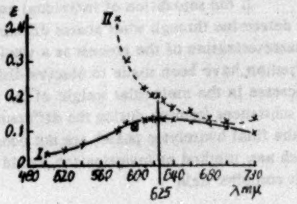


Fig. 2.

a) In a solution of tripeptide complex there appears a dipeptide complex. If glycylglycine dipeptide and hydrated oxide are added to a solution of diglycylglycine tripeptide complex (Fig. 1, curve I; Table 2, column I), then a change occurs after 1.5 hours, as shown by curve II, Fig. 1 (Table 2, colume II).

Comparing curve II with curve I, it can be noted that in curve II a maximum at wave length 625 m μ appears (the characteristic maximum for the dipeptide Ni-complex) and an increase in absorption intensity occurs in the region 600 to 730 mμ.

Therefore, the appearance of a dipeptide complex against a tripeptide complex background is characterized by the appearance of a maximum. Consequently, if dipeptides are going to appear in solution during the process of albumin disintegration, their presence can be detected by the appearance of a maximum in the curve. The authors will further demonstrate that actually such a phenomenon is observed under defined conditions during a given phase of albumin disintegration.

b) In a solution of dipeptide (glycylic) complex there appears a tripeptide (glycylic) complex. In a given experiment a blue solution of the nickel biuret complex of the dipeptide was prepared, which is characterized by curve I on Fig.2 and the data in Table 2, column III. To this solution was added a tripeptide and hydrated nickel oxide. The solution changed in color – it became orange. Spectrophotometric curve II, Fig.2; Table 2, column IV indicates that the course of the dipeptide complex (I) curve changed, the intensity of absorption raised sharply from 480 to 625 mμ; the curve resembles the one characteristic for the tripeptide complex, but along with this there is a maximum at wave length 625 mμ and an increase in the absorption intensity on the section from 625-730 mμ which is characteristic for the dipeptide complex.

c) In a solution of the tetrapeptide there appears a dipeptide complex. A solution of the tetrapeptide nickel biuret complex, canary-yellow in color, was prepared. The spectrophotometric curve for this solution is presented in Fig. 3, curve I, and by Table 2 data, column V. Dipeptide and hydrated nickel oxide were added to the solution, the coloration of the solution after 1.5 hours was hardly changed visibly, but the spectrophotometric curve displayed characteristic changes (curve II). In Fig. 3 it can be seen that curve II differs from curve I in that there appears a small maximum at wave length 615 mμ; absorption all along the spectrum is considerably increased, especially at wave lengths 580-730 mμ. The appearance of the dipeptide complex in a solution of tetrapeptide complex is evidently similar to the experiment with the tripeptide complex, i.e., there appears a maximum on a well-defined section of the wave length against the background of a curve which does not possess a maximum. Moreover, the absorption in the range 560-730 mμ increases noticeably.

TABLE 2

Spectrophotometric Investigation of Nickel Biuret Complexes of Peptide Mixtures

Wave length λ (in mμ)	Value for optical density, ε							
	Tripeptide complex 0.034 M	Mixture of tripeptide 0.034 M and dipeptide 0.049 M complexes	Dipeptide complex 0.043 M	Mixture of dipeptide 0.043 M and tripeptide 0.04 M complexes	Tetrapeptide complex 0.05 M	Mixture of tetrapeptide 0.09 M and dipeptide 0.066 M complexes	Glycocoll complex 0.05 M	Mixture of glycocoll 0.05 M and tripeptide 0.03 M complexes
	I	II	III	IV	V	VI	VII	VIII
480			0.039				0.008	
500			0.033				0.005	
520			0.046				0.0125	
540			0.0505				0.018	
560			0.083		0.1551	0.241	0.0378	
580	0.3514	0.46	0.109	0.409	0.0520	0.1299	0.056	0.345
590	0.2174	0.371	0.122	0.308	0.0374	0.107	0.068	0.230
600	0.1350	0.32	0.112	0.275	0.0354	0.099	0.080	0.160
610	0.1061	0.292	0.133	0.222	0.0284	0.093	0.082	0.120
615	0.0970	0.286	0.1308	0.2104	0.0260	0.095	0.087	0.114
620	0.0833	0.272	0.133	0.199	0.0260	0.093	0.086	0.102
625	0.0578	0.28	0.137	0.204	0.0257	0.088	0.085	0.089
630	0.0566	0.25	0.136	0.187	0.0220	0.0823	0.089	0.082
640	0.0518	0.238	0.134	0.167	0.0190	0.086	0.085	0.070
660	0.030	0.20	0.127	0.155	0.020	0.075	0.077	0.050
680	0.0310	0.187	0.124	0.138	0.0129	0.068	0.061	0.041
700	0.0243	0.174	0.112	0.1203	0.0119	0.063	0.047	0.038
730	0.0160	0.171	0.095	0.130	0.0109	0.053	0.028	0.034

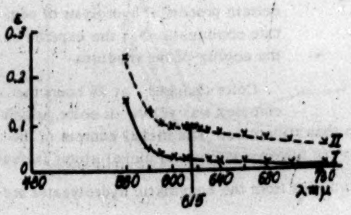


Fig. 3.

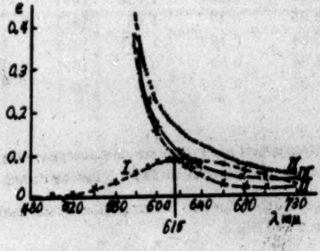


Fig. 4.

d) Formation of the nickel biuret complex from a mixture of glycylic tripeptide and glycocoll. Likewise examined was the effect of tripeptide complex formation in the presence of the amino acid of glycocoll. A solution of nickel sulfate was added to a mixture of the tripeptide and glycocoll in alkaline solution, and the spectrophotometric curve was photographed after a given lapse of time. The optical densities are cited in Table 2, column VII. On Fig. 4 is pictured curve III corresponding to this solution. Here also is plotted curve II, corresponding to the nickel biuret complex of tripeptide, and curve I—to the complex of glycocoll. Curve IV represents an arithmetically-obtained sum, ε, of I and II curves. It can be seen that curve III coincides neither with curve IV nor curve II. This indicates that glycocoll under these conditions participates only partially in the reaction, by which is explained the higher absorption for curve III on the wave length section 615-730 mμ, as compared with curve II.

Moreover, the difference between curves III and IV indicates that the biuret complex of the tripeptide was completely formed, and that glycocoll reacted partially at the same time, possibly forming a new type of complex.

The experiments which have been described give some idea of the change in character of the absorption for a peptide complex when there appears in the solution a new peptide of different chain length.

Following are the principal observations.

1) Appearance of a dipeptide complex in a solution of tripeptide complex causes an intensification of absorption in the range 560-573 mμ, and especially at wave length 625-615 mμ, which is denoted on the curve by formation of a maximum.

2) Appearance of a dipeptide complex in a solution of tetrapeptide complex likewise leads to an increase in absorption at wave length 560-730 mμ.

3) Appearance of an amino acid in a solution of tripeptide complex causes a small increase in absorption at 560-730 mμ.

3. Investigation of Enzymatic Hydrolysis of Gelatin.

Gelatin solution (2%) was reacted with pepsin (0.2% solution) at 37°, pH = 1.5-2 for 245 hours. As indicators to characterize the process, the following were chosen: 1) total nitrogen content in test sample (by Kjeldahl); 2) free α-amino nitrogen content (according to Van Slyke); 3) the character of the light absorption by the nickel biuret complex (spectrophotometric determination of the biuret complex solution); 4) nickel content of the biuret complexes of each sample.

The analyses are summarized in Table 3 for enzymatic hydrolysis carried out for 245 hours duration.

TABLE 3

Enzymatic Hydrolysis of Gelatin Solution (2%) with Pepsin (0.2%) at 37°, pH = 1.5-2.0.

Time from start of reaction (in hrs)	In 1 ml of sample				Complex color
	Total nitrogen (in mg)	Amino nitrogen (in mg)	Content		
			Ni (in mg)	in g-atoms $N_{tot.}/Ni$	
0	3.356	0.15	1.4	10:1	Orange
5	3.35	0.161	1.025	14:1	Orange-yellow
11	3.35	0.17	1.05	13:1	Orange-yellow
25	3.34	0.187	1.075	13:1	Yellow
49	3.34	0.32	0.9	16:1	Yellow
245	3.34	0.334	0.9	16:1	Yellow

It should be noticed that the amino nitrogen remained practically unchanged for 25 hours. At 49 hours the amino nitrogen doubled, and then remained constant for two hundred hours.

Judging from the data which indicated the free amino nitrogen change, the peptide combinations did not break during the first 25 hours. Before anything else there began a certain process of hydrolysis of peptide combinations at the expense of the acidity of the medium.

Color changes: at 25 hours the complex was yellow in color, which indicated the formation of complexes characteristic for longer chains than tripeptide. The nickel content of the complex decreases, as the data of Table 3 indicate, and the ratio between nitrogen atoms and nickel atoms increases.

The spectrophotometric investigation of the nickel biuret complexes from the enzymatic hydrolyzates are cited in Table 4 and Fig.5.

Fig. 5 indicates that with lapse of time there is observed a decrease in the intensity of absorption of the biuret complexes from sample to sample along the spectrum. After 49 hours the absorption intensity remains unchanged. A decreased intensity likewise indicates the formation of peptide complexes of longer chain than tripeptide. As was demonstrated earlier, nickel biuret complexes of peptides with longer chains than the tripeptide form yellow complexes possessing decreased absorption intensity in the range 580-730 mμ, as compared with the tripeptide orange complex. Changes in the absorption character by biuret complexes from the peptic digestion of gelatin indicate the formation of longer chains than tripeptide. And — what is especially important — the chain lengthening does not involve breaking of peptide combinations inasmuch as the free α-amino nitrogen remains almost unchanged.

TABLE 4

Spectrophotometric Investigation of the Nickel Biuret Complexes from the Enzymatic Hydrolysis of 2% Gelatin Solution

Wave lengths λ (in mμ)	Value for optical density, ε					
	Sample 1 at 1 hr	Sample 2 at 5 hrs	Sample 3 at 11 hrs.	Sample 4 at 25 hrs.	Sample 5 at 49 hrs.	Sample 6 at 245 hrs.
480						
500						
520						
520						
560		0.3960	0.3275	0.3260	0.2580	0.3420
580	0.324	0.2260	0.1650	0.1647	0.1240	0.160
590	0.230	0.1651	0.1109	0.1090	—	0.090
600	0.173	0.1468	0.0809	0.0790	0.0570	0.0620
610	0.152	0.1313	0.0725	0.0666	0.0476	0.0586
615	0.146	0.1208	0.0630	0.0598	—	0.0403
620	0.136	0.1166	0.0598	0.0564	—	0.0376
625	0.129	0.1125	0.0630	0.0523	0.0353	0.0330
630	0.126	0.1080	0.0495	0.0510	—	0.0290
640	0.124	0.1070	0.0440	0.0440	—	0.0260
660	0.133	0.0898	0.0360	0.0377	—	0.0140
680	0.146	0.0808	0.0296	0.0303	0.0190	0.0120
700	0.157	0.0805	0.0294	0.0296	—	0.0120
730	0.167	0.0640	0.0273	0.0174	—	0.0145

Having in mind the structure of albumin as proposed by Gavrilov [3], such a process can be presented as follows: under the influence of the enzyme, diketopiperazine rings break off, the peptide chain lengthens to hexapeptide, which gives possibility for the formation of the yellow biuret complex. The ratio between total nitrogen and nickel should increase at this time, a fact which is confirmed by the analytical data cited in Table 3.

4. Investigation of the Alkaline Hydrolysis of Gelatin

Gelatin solution (2%) was reacted with 2% sodium hydroxide at 100° for 40 hours. Samples were taken at specific intervals and analyzed for total and amino nitrogen contents. Biuret complex solutions were made from each sample, which were spectrophotometrically analyzed for metal content in complex. The changes which are observed upon alkaline hydrolysis of gelatin are of different character in comparison to those described above for the enzymatic hydrolysis. The coloration of the complexes indicates an entirely different picture of disintegration. Table 5 includes the basic data obtained during the investigation. During the disintegration process the quantity of free α-amino hydrogen grows continuously,being especially strong during the first 6 hours.

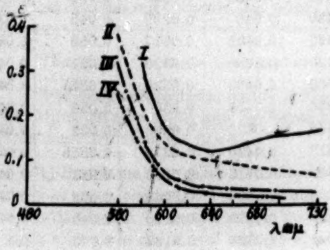


Fig. 5.

The nickel content in the complex slowly decreases during the first 2 hours, and then decrease in nickel proceeds more rapidly.

The results of the spectrophotometric investigation are cited in Table 6 and on Fig. 6.

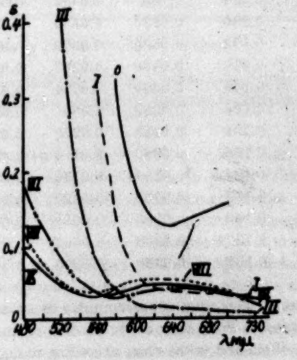


Fig. 6.

There are three phase changes apparent in the absorption character.

1) During the first 1.5 hours of hydrolysis a sharp decrease in absorption intensity occurs all along the

TABLE 5

Alkaline Hydrolysis of Gelatin Solution (2%) with 2% NaOH at 100°

Time from start of reaction (in hrs)	In 1 ml of sample				Complex color
	Total nitrogen (in mg)	Amino nitrogen (in mg)	Content		
			Ni (in mg)	in g-atoms $N_{tot.}/Ni$	
0	3.26	0.19	1.4	10:1	
0.5	3.24	0.67	1.33	11:1	Orange
1	3.11	1.057	1.25	11:1	Orange-yellow
1.5	3.11	1.27	1.12	11:1	Yellow
2	3.11	1.36	1.05	12:1	Yellow with green shade
6	3.11	1.82	0.79	16:1	Yellow-green
14	3.11	1.92	0.62	20:1	Green-yellow
25	3.028	2.02	0.45	28:1	Green
30	3.028	2.58	0.75	17:1	Green with blue shade
40	3.028	2.58	0.67	19:1	Green-blue

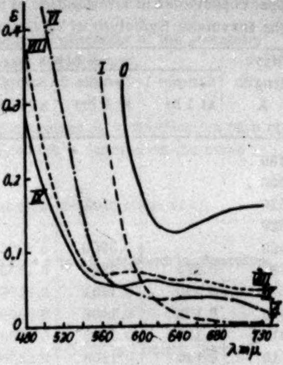


Fig. 7.

TABLE 6

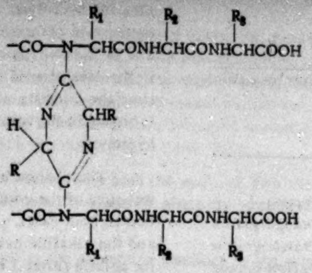
Spectrophotometric Investigation of the Nickel Biuret Complexes from the Alkaline Hydrolysis of 2% Gelatin Solution

Wave lengths λ (in mμ)	Values for optical density, ε									
	Sample 0 at 0 hr	Sample 1 at 0.5 hrs.	Sample 2 at 1 hr.	Sample 3 at 1.5 hrs	Sample 4 at 2 hrs.	Sample 5 at 6 hrs	Sample 6 at 14 hrs	Sample 7 at 25 hrs	Sample 8 at 30 hrs	Sample 9 at 40 hrs
480							0.2430	0.1720	0.117	0.094
500						0.3067	0.1630	0.1203	0.075	0.058
520				0.3990	0.3405	0.1860	0.1008	0.080	0.0475	0.042
540			0.3217	0.1650	0.2070	0.1110	0.0620	0.040	0.040	0.035
560		0.3010	0.1507	0.0740	0.1030	0.0540	0.0480	0.0338	0.035	0.033
580	0.324	0.140	0.0770	0.0340	0.0470	0.0430	0.040	0.0299	0.045	0.035
590	0.230	0.0830	0.0450	0.0290	0.0430	0.0367	0.0453	0.0317	0.050	0.040
600	0.173	0.0620	0.0370	0.0250	0.0364	0.0330	0.0480	0.0330	0.051	0.045
610	0.152	0.0466	0.0337	0.0150	0.0272	0.0363	0.0490	0.0330	0.0525	0.048
615	0.146	0.0440	0.0334	0.0180	0.0236	0.0350	0.0458	0.030	0.053	0.046
620	0.136	0.0399	0.030	0.0179	0.0230	0.0380	0.0420	0.0290	0.052	0.043
625	0.129	0.0355	0.0220	0.0190	0.0234	0.0417	0.0430	0.0270	0.0515	0.043
630	0.126	0.0360	0.0190	0.0136	0.0222	0.0392	0.0410	0.0260	0.051	0.042
640	0.124	0.0354	0.0170	0.0133	0.0199	0.0350	0.0376	0.0240	0.050	0.041
660	0.133	0.0340	0.0120	0.0110	0.0213	0.0330	0.0390	0.0190	0.048	0.042
680	0.146	0.0360	0.0090	0.0091	0.0174	0.0340	0.0320	0.0167	0.043	0.0375
700	0.157	0.0306	0.0090	0.0094	0.0170	0.0274	0.0358	0.0188	0.036	0.031
730	0.167	0.0280	0.0070	0.0052	0.0178	0.0219	0.0285	0.0118	0.020	0.0205

spectrum. The color of the complex becomes yellow: formation of longer chains than tripeptides proceeds with a simultaneous sharp increase in the free α-amino groups. The disintegration involves breaking peptide combinations in the chain and in the rings according to the scheme: (see top of next page).

During this length of time the albumin molecule disintegrates. A mixture of fragments remains, which is probably quite homogeneous by the length of the peptide chain.

2) After 2 hours of hydrolysis there occurs a small maximum absorption at wave lengths 625-630 mμ. Absorption from 480 to 600 mμ is decreased, from 600-730 mμ it increases. The color of the complex acquires



(II)

(I)

a greenish shade, which indicates the appearance of the blue color complexes against the background of yellow complexes. The changes all-told undoubtedly indicate the appearance of chains of dipeptides in the hydrolyzate which should appear at the expense of tetrapeptide disintegration.

3) At 30 hours there is an intensive decrease in absorption at wave lengths from 480 to 600 mμ and a certain increase in absorption from 600 to 730 mμ. The absorption maximum is evidently getting brighter. The complex color is changing from green-yellow through yellow, acquiring a blue shade. By that time dipeptides already predominate in the hydrolyzate.

4) At 40 hours there is observed a decrease in absorption intensity all along the spectrum from 480 to 730 mμ. The complex color is green-blue. It is possible that at this stage the appearance of amino acids begins at the expense of dipeptide splitting. Alkaline hydrolysis at 100° shows altogether a strong disruptive action on the albumin molecule, which is indicated by the intensive increase in free α-amino nitrogen. Nevertheless, dipeptides appear only after 2 hours of hydrolysis, and amino acids at 40 hours. This is because the stability of the peptide combination varies according to the compound in which it finds itself.

5. Investigation of Acid Hydrolysis of Gelatin

Gelatin solution (2%) was hydrolyzed with 2% hydrochloric acid at 100° for 40 hours. In the time specified samples were taken which were analyzed for total and for amino nitrogen contents. The nickel biuret complex solutions were analyzed for nickel content in the complex, and the character of the light absorption was determined. The analytical results are cited in Table 7.

Table 7 shows that the amino nitrogen increases gradually during the first two hours, then at 30 hours the increase has become more intense, and after 30 to 40 hours of hydrolysis,free amino nitrogen continues to increase slowly.

The nickel content in the complex fluctuates somewhat,but has a general tendency to decrease.

The spectrophotometric results of investigation are cited in Table 8 and on Fig.7. The character of the changes which develop during acid hydrolysis basically resemble the picture described for alkaline hydrolysis. However, there are some peculiarities.

1) During the first phase of acid hydrolysis a decrease in absorption is observed during the first hour, especially at wave lengths 690-730 mμ (Table 8). Absorption at 625 mμ reaches at that time its lowest value. In the alkaline hydrolysis experiment by that time (after 1 hour) the lowest absorption is likewise evident at 625 mμ, i.e., both in the case of alkaline as well as acid hydrolysis of gelatin, the maximum quantity of peptides capable of forming the yellow complex are present 1 hour from the start of the hydrolysis. Inasmuch as in this and the other case the process is accompanied by a continuous, intense increase in free amino nitrogen, apparently there is proceeding an energetic disruption of peptide bonds. At the same time, increase in amino nitrogen proceeds more intensely in the case of alkaline hydrolysis than in the case of acid hydrolysis. For the same time (1 hour) a greater quantity of free amino nitrogen is present in the sample from alkaline hydrolysis as compared with a sample at 1 hour from acid hydrolysis. But inasmuch as the intensity of the absorption by the nickel complexes of these two samples is very close, it should be assumed that in the case of acid hydrolysis disintegration proceeds not only with disruption of the peptide bond,but also without disruption (with splitting of the diketopiperazine rings).

2) After carrying out the acid hydrolysis for 1 hour, the decrease in absorption intensity by the complexes proceeds for wave lengths 480 to 600 mμ, with an increase in absorption intensity at wave lengths from 600 to 730 mμ. At the same time the decrease in absorption at short waves proceeds less vigorously than in the case of

TABLE 7

Acid Hydrolysis of Gelatin Solution (2%) with 2% HCl at 100°

Time from start of experiment (in hrs)	Total nitrogen (in mg)	Amino nitrogen (in mg)	Content		Complex color
			Ni (in mg)	in g-atoms $N_{tot.}/Ni$	
0	3.26	0.19	1.4	10:1	
0.5	3.17	0.44	0.95	15:1	Orange
1	3.17	0.63	0.8	17:1	Orange-yellow
1.5	3.1	0.65	1.12	12:1	Orange-yellow
2	3.09	0.68	1.2	11:1	Yellow-orange
6	3.04	1.047	1.2	11:1	Yellow
14	3.04	1.54	1	13:1	Yellow with slight greenish shade
25	3.04	1.83	1.07	12:1	Yellow-green
30	3.04	2.16	1.07	12:1	Yellow-green
40	3.04	2.25	0.56	24:1	Green

alkaline hydrolysis. However, the increase in absorption at wave lengths 600 to 730 mμ proceeds more vigorously in the case of acid hydrolysis. By this time the quantity of free amino nitrogen is higher in the sample from the alkaline hydrolysis.

The change in the absorption intensity of the complexes indicates that in both cases, i.e. in the acid and the alkaline hydrolysis processes for gelatin (after 1 hour for the acid and 1.5 hours for the alkaline), there begin to appear dipeptides in the hydrolyzate, according to which the increased intensity of absorption at 600-730 mμ is understandable. At the time in question the formation of dipeptides proceeds more rapidly in the case of acid hydrolysis.

In the case of alkaline hydrolysis, dipeptides appear as the result of splitting of tetrapeptides, which were formed during the first 1.5 hours of hydrolysis. In such case the appearance of blue complexes should proceed simultaneously with the disappearance of the yellow ones, i.e. intensification of absorption in the 600-730 mμ range should be accompanied by a considerable absorption decrease in the section 480-600 mμ. The authors show in Fig. 6, curve VIII, that exactly just such a change in the absorption character takes place in the case of alkaline hydrolysis.

TABLE 8

Spectrophotometric Investigation of the Nickel Biuret Complexes from the Acid Hydrolysis of 2% Gelatin Solution

Wave lengths λ (in mμ)	Value of the optical density, ϵ									
	Sample 0 at 0 hr	Sample 1 at 0.5 hrs	Sample 2 at 1 hr	Sample 3 at 1.5 hrs	Sample 4 at 2 hrs	Sample 5 at 6 hrs.	Sample 6 at 14 hrs	Sample 7 at 25 hrs	Sample 8 at 30 hrs	Sample 9 at 40 hrs
480									0.3877	0.2850
500							0.4313	0.3462	0.2516	0.2166
520						0.420	0.2705	0.1680	0.1626	0.1345
540			0.4544	0.5149	0.4710	0.2345	0.1772	0.1099	0.0944	0.0786
560		0.3320	0.2264	0.2615	0.2280	0.1070	0.0746	0.070	0.070	0.060
580	0.324	0.1460	0.1151	0.1356	0.1188	0.0591	0.0579	0.0599	0.0720	0.0270
590	0.230	0.0920	0.0678	0.0776	0.0737	0.0461	0.0530	0.0590	0.0740	0.0581
600	0.173	0.0550	0.0447	0.0578	0.0489	0.0335	0.0459	0.0654	0.0760	0.0646
610	0.152	0.0460	0.0317	0.0356	0.0454	0.0393	0.0460	0.0570	0.0734	0.0667
615	0.146	0.0350	0.0290	0.030	0.0408	0.0371	0.040	0.0609	0.0728	0.0701
620	0.136	0.0277	0.0217	0.0288	0.0399	0.0399	0.0372	0.0601	0.0716	0.0660
625	0.129	0.0250	0.0195	0.0204	0.0314	0.0317	0.0352	0.0572	0.0697	0.061
630	0.126	0.0150	0.0184	0.0167	0.0311	0.0305	0.0401	0.0564	0.0672	0.0582
640	0.124	0.0130	0.0153	0.0144	0.0285	0.0262	0.0380	0.0581	0.0655	0.0628
660	0.133	0.0071	0.0095	0.0155	0.0248	0.0180	0.0386	0.0601	0.0680	0.0570
680	0.146	0.0047	0.0102	0.0139	0.0207	0.0191	0.0401	0.0559	0.0607	0.0525
700	0.157	0.060	0.0104	0.0117	0.0226	0.0196	0.0382	0.0512	0.0560	0.0496
730	0.167	0.0620	0.0086	0.0130	0.0184	0.0202	0.0254	0.0360	0.0487	0.0466

Upon acid hydrolysis the appearance of dipeptides should proceed not only at the expense of tetrapeptides by splitting, but also at the expense of the free diketopiperazine rings which are split during the first hours of hydrolysis. Only in such cases will the appearance of blue complexes proceed without the simultaneous extensive decrease in the quantity of yellow complexes. In the acid hydrolysis from 1 hour to 30 hours quite characteristic is the more significant increased absorption at the 600-730 mμ section than the decreased absorption in the 480-600 mμ range (Fig. 7, curve VIII).

3) After 30 hours for both the acid and alkaline hydrolysis of gelatin, the decreased absorption intensity by the biuret complexes is observed along the whole spectral section from 480 to 730 mμ (Fig. 6, curve IX; Fig. 7, curve IX).

Inasmuch as the absorption intensity by the amino acid complexes is considerably less than for the dipeptide, it is possible that a decrease in intensity of absorption in both cases can be explained by the appearance of amino acids at the expense of dipeptides which are disrupted.

Comparing with one another the results obtained from hydrolysis experiments on gelatin at various conditions, it can be seen that use of spectrophotometry of the nickel biuret complexes allows one to note the peculiarity of each process. The picture of these transformations, which undergo complex formation, and also the character of the absorption vary depending upon the conditions of hydrolysis.

No doubt this diversity should be connected with diverse chemical reactions. The old peptide theory of Hofmeister-Fischer cannot explain this diversity of reactions, since disruption of the molecule from the point of view of this theory should proceed only in the direction of shortening the chain.

The albumin molecule structural pattern proposed by a new theory of Zelinsky-Gavrilov [4], in spite of its probability and substantiation, is still for the time being a working hypothesis. Therefore, the schemes for disruption of the albumin molecule, which were cited by the authors in explaining the denoted changes in absorption character also represent only a working scheme.

EXPERIMENTAL

Formation of Nickel Biuret Complex in Mixtures of Glycylic Peptides. Experiment a. A solution of of biuret Ni-complex of tripeptide was prepared. A weighed portion of tripeptide 0.0967 g was dissolved in 8 ml of water, 4 ml of KOH (2N) and 3 ml $NiSO_4$ (0.21 M). After one hour the excess hydroxide was filtered off. The solution was orange in color, and a spectrophotometric curve was taken (Table 2; Fig. 1, curve I). The spectrophotometry was carried out in a Koenig-Martens apparatus set-up [5]. Then to 13 ml of the same solution, a weighed portion of dipeptide, 0.0848 g was added and Ni introduced in the form of the hydroxide, the excess of which was filtered off after 1.5 hours standing. The color of the solution became lighter and the spectrophotometric curve was taken (Table 2; Fig. 1, curve II).

Experiment b. The biuret of the dipeptide Ni-complex was prepared. A weighed portion of the dipeptide, 0.0848 g was dissolved in 8 ml of water, 4 ml of KOH (2 N) and 3 ml of $NiSO_4$ (0.21 M). After standing 1.5 hours, the excess hydroxide was filtered off, and the solution had a blue color; the spectrophotometric curve was taken (Table 2; Fig. 2, curve I). To 12 ml of the same solution 0.0991 g of tripeptide was added, Ni was introduced in the form of its hydroxide. The solution turned from blue to orange. The spectrophotometric curve was taken (Table 2; Fig. 2, curve II).

Experiment c. The biuret complex of the tetrapeptide was prepared. A weighed portion of the tetrapeptide 0.1845 g, was dissolved in 10 ml of water, 4 ml of KOH (2 N) and 3 ml of $NiSO_4$ (0.21 M). After standing 1.5 hours the excess hydroxide was filtered off, and the color of the solution was yellow. The spectrophotometric curve was taken (Table 4; Fig. 4, curve I). To 12 ml of the same solution 0.0833 g of dipeptide was added, Ni was introduced in the form of its hydroxide. After standing 1.5 hours the excess nickel hydroxide was filtered off. Color of the solution remained yellow. The spectrophotometric curve was taken (Table 4; Fig. 4, curve II).

Experiment d. To a weighed portion of tripeptide, 0.0944 g, and of glycocoll, 0.0571 g, 9.5 ml of water, 3 ml of NaOH and 2.5 ml of $NiSO_4$ (0.21 M) were added. After standing 1.5 hours, the Ni hydroxide was filtered off, the color of the solution being orange. The spectrophotometric curve was taken (Table 4; Fig. 5, curve III).

Enzymatic Hydrolysis of Gelatin. 70 ml of water was poured over 4 g of gelatin for the night. On the following day, hydrochloric acid was added by indicator so that the pH = 1.5-2, and then 0.4 g of pepsin dissolved in 40 ml of NaCl (0.1%) was added, water, and again acid until pH = 1.5-2, so that the total volume of hydrolyzate was 200 ml. The experiment was carried out in a thermostatic bath at 37°.

During the experiment samples were taken after 5, 11, 25, 49 and 245 hours, in which were determined: total nitrogen according to Kjeldahl; amino nitrogen according to Van Slyke; the spectrophotometric curves of the nickel biuret complexes for each sample taken (Koenig-Martens apparatus), and the colorimetric determination of Ni in the biuret nickel complexes was carried out for each sample taken.

For amino nitrogen determination 1 ml samples were taken. For spectrophotometry and colorimetry the biuret complex was prepared in the following manner: to 6 ml of the sample of hydrolyzate was added 5.5 ml of water, 1.5 ml of NaOH (3 N) and 2 ml of $NiSO_4$ (0.21 M), and after 1.5 hours the Ni hydroxide precipitate was filtered off and the spectrophotometric curve was taken. Ni was determined colorimetrically in the same complex. The final result was reduced by recalculation to the quantity of Ni which was contained in 1 ml of the gelatin solution.

Alkaline Hydrolysis of Gelatin Solution. 100 ml of water was poured over 4 g of gelatin for the night. On the following day 100 ml of NaOH (4%) was added to the gelatin solution. The total volume was 200 ml. Hydrolysis was carried out on a water bath in a flask equipped with reflux condenser. During the experiment samples were taken after 30 minutes, 1, 1.5, 2, 6, 14, 20, 30 and 40 hours. In them was determined: amino nitrogen according to Van Slyke (samples from 2 to 0.5 ml); total nitrogen according to Kjeldahl; spectrophotometry of the biuret complexes of each sample was carried out and the Ni content of the complex was determined.

Acid Hydrolysis of Gelatin Solution. 100 ml of water was poured over 4 g of gelatin and left for the night. On the following day 100 ml of HCl (4%) was added. Hydrolysis was carried out at 100°.

During the experiment samples were taken after 30 minutes, 1, 1.5, 2, 6, 14, 25, 30 and 40 hours. Determined was: total nitrogen according to Kjeldahl, amino nitrogen according to Van Slyke; spectrophotometry of the Ni biuret complexes for each sample was carried out and Ni was colorimetrically determined in the complex.

SUMMARY

1. The appearance of the nickel biuret complex of the dipeptide (glycylic) in a solution of the nickel biuret complex of the tripeptide (glycylic), and also in the solution of tetrapeptide (glycylic) causes intensification of absorption in the range 560-730 mμ. The absorption is particularly increased in the 615-625 mμ range, which is indicated on the curve in the form of a maximum.

2. In the case of enzymatic (peptic) hydrolysis of gelatin, the change in absorption character of the nickel biuret complexes of the hydrolyzates discloses an increasing quantity of peptides with chains longer than the tripeptide. The process proceeds without rupturing the peptide bonds.

3. At 40 hours of alkaline hydrolysis for gelatin, three basic phases were observed in the character change of absorption for the nickel biuret complexes:

a) During the first 1.5 hours, with intensive increase of α-amino nitrogen a sharp absorption decrease proceeds all along the spectrum, the color of the complex becoming yellow—all of which indicates the formation of longer chains than the tripeptide.

b) After two hours of hydrolysis there appears on the absorption curve a maximum at wave length 625-630 mμ; the absorption from 480 to 600 mμ decreases, from 600 to 730 mμ it increases. The color of the complex acquires a green shade. All of these changes indicate the appearance in the hydrolyzate of dipeptide chains. This process continues up to 30 hours.

c) After 30 hours decreased absorption intensity is observed all along the spectrum. The color of the complex is greenish-blue. At this stage the appearance of amino acids is possible.

4. During the process of acid hydrolysis of gelatin there are observed changes in the character of the absorption by the nickel biuret complexes, resembling in many ways the ones indicated for alkaline hydrolysis. The difference is contained in the following:

a) The formation of peptides with longer chain length than tripeptide proceeds, during the first stage of disintegration, in the case of acid hydrolysis, not only with liberation of α-amino nitrogen, but also without the rupture of peptide bonds, which is manifested by the same absorption intensity and smaller α-amino nitrogen content in the sample from acid hydrolysis.

b) The process of peptide formation, giving blue biuret complexes (dipeptides) begins in the case of acid hydrolysis after 1 hour and proceeds vigorously.

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V. AROMATIZATION OF 2,3,3-TRIMETHYL-1-BUTENE WITH CHROMIUM CATALYSTS

R. D. Obolentsev and N. I. Kuvshinova

The literature on aromatization of alkenes, with principal chain length less than 6 carbon atoms, is very scant. In the papers of Goldwasser and Taylor [1,2], are reported the results of the aromatization of 2-methyl-2-pentene, 3-methyl-2-pentene, and 2-ethyl-1-butene with chromic oxide: i.e. alkenes with 5 carbon atoms in the principal chain. The data on the aromatization of alkenes with four atoms in the principal carbon chain is limited to the report on the two orientating experiments of the aromatization of 2,3,3-trimethyl-1-butene made by one of the authors in 1947 [3]. Knowledge on the aromatization of alkenes of this structure is of great interest in connection with the question of the mechanism of aromatization of aliphatic hydrocarbons not containing six or more carbon atom chains.

A. F. Plate [1] carefully examined the mechanism of the aromatization reaction of parafin hydrocarbons; but he did not concern himself with the question of the isomerization of alkenes, structurally of interest to the authors, during the aromatization. A. D. Petrov [4], reporting the dynamic formation of isoalkenes during polymerizations, likewise did not concern himself with the question of their formation during aromatizations, presupposing that it would be discussed in Plate's monograph.

The mechanisms, proposed by Rideal [5], Raik [6] for the aromatization of alkanes with 5 carbon atoms in the principal chain, can be extended for the aromatization of 2-ethyl-1-butene, 3-methyl-2-pentene, 2-methyl-2-pentene with chromium catalysts, if the formation of rings by means of the doublet index [6] is allowed. Such proposed mechanisms contain many shortcomings, which were pointed out for the aromatization of alkanes (carefully examined by Plate [1]). In support of their mechanisms, the above authors cite that such hydrocarbons as 2,3-dimethylbutane, i.e. alkanes with four carbon atoms in the principal chain, do not aromatize. The aim of the present investigation was to verify the previously discovered [3] aromatization of 2,3,3-trimethyl-1-butene, i.e., an alkene with four carbon atoms in the principal chain, and to study it in greater detail, if possible.

EXPERIMENTAL

2,3,3-Trimethyl-1-butene (98.5 g) was prepared both from acetone and methanol by the method reported by one of the authors in a previous communication [7]. That obtained from the former, b.p. 77.5-78.5°; bromine number – 160.8; that obtained from the latter – b.p. 78-78.5°. Literature results: b.p. – 78°; bromine number – 163° [8];

Thermodynamic calculations, initially made in order to see if the isolated aromatization of 2,3,3-trimethyl-1-butene was thermodynamically feasible, showed that, at atmospheric pressure and 450-600°, this reaction would occur practically without reversal.

Experiments on the aromatization of 2,3,3-trimethyl-1-butene were conducted with two examples of chromium catalysts:

1) "chromic oxide on aluminum oxide", prepared by the simultaneous precipitation of chromic and aluminum hydroxides from a mixture of solutions of aluminate and chromate;

2) "chromic oxide", prepared by the reduction of ammonium bichromate with methanol followed by the precipitation of the hydroxide with ammonia solution.

The experiments were conducted in a continuous type apparatus with a "Pyrex" glass reactor. An analogous apparatus, as well as the experimental method, are reported in the previous communication [9].

The gaseous reaction products were either analyzed by means of a VTI apparatus, or were isothermally fractionated. The molecular weight (cryoscopic method) and the bromine number (Halpern and Vinogradova method [10]); the unsaturation, as mono-olefinic hydrocarbons, was calculated from these results. The aromatic hydrocarbons were determined by means of the specific and relative dispersion [11,12]. The saturated residue was determined by difference.

The results of the experiments on the aromatization of 2,3,3-trimethyl-1-butene are given in Tables 1-3. The materials balance of the experiments, as well as the yields of the hydrocarbons and the aromatics expressed as moles per 100 moles of the hydrocarbon used, are given in Table 1. The analytical results of the gaseous and liquid products evolved are given in Table 2.

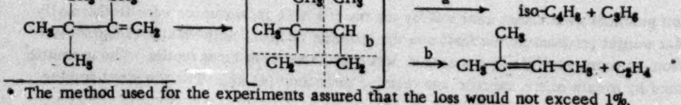
An examination of Table 1 shows that the number of moles of ΣC_4H_8, C_4H_{10} is approximately equal to the number of moles of ΣC_3H_6, C_3H_8. In addition to butanes and butylenes, and propanes and propylenes in the gaseous products, hydrogen, methane, ethylene, and ethane are present in considerable amounts.

TABLE 1

Yield of liquid and gaseous products from experiments on the aromatization of 2,3,3-trimethyl-1-butene

Conditions and experimental results	Catalyst and experiment number						
	Chromic oxide on aluminum oxide			Chromic oxide			
	5	4	6	3	7	2	1
Temperature °C	580	580	530	580	580	550	510
Rate of input (volume/volume of catalyst, in hours)	3	1.2	3	3	1.6	1.0	1
Duration of experiment (in min.)	15	23	16	30	50	90	90
Balance (in % by weight):							
gaseous products	31.3	52.0	24.4	21.4	38.2	18.2	14.9
liquid products	37.8	10.7	63.9	74.1	50.0	63.6	72.7
loss as coke*	30.9	37.3	11.7	4.5	11.8	18.2	12.4
Yield of gas (in moles per 100 moles of 2,3,3-trimethyl-1-butene):							
ΣC_nH_{2n+2}	76.6	110.2	35.8	28.8	85.6	30	29.6
ΣC_nH_{2n}	29.8	23.9	17.8	22.1	39.0	16.3	3.2
ΣC_3H_6, n-C_4H_8	15.6	11.2	8.2	10.8	17.1	6.6	2.0
ΣC_3	15.6	13.5	10	–	–	–	–
ΣC_4	18.8	14.3	10.8	–	–	–	–
H_2	107.5	145.0	59.5	22.0	34.0	40.0	11
CH_4	57.0	67.0	18.8	–	–	–	–
C_2H_6	12.0	31.4	10.8	–	–	–	–
C_2H_4	3.0	7.9	3.2	1.3	10.2	2.6	1.2
C_3H_8	4.8	7.3	4.2	–	–	–	–
C_3H_6	10.8	6.2	5.8	–	–	–	–
ΣC_4H_{10}	2.8	4.5	2.0	–	–	–	–
n-C_4H_8	4.8	5.0	2.4	–	–	–	–
iso-C_4H_8	11.2	4.8	6.4	10.0	11.7	7.1	0.0
Total yield of gas	215	281	114	74	160	86	44
Amount of 2,3,3-trimethyl-1-butene transformed (in mol. %)							
of ΣC_3, C_4**	17	14	10	–	19	–	–
of ΣC_2, C_5**	15	39	14	–	31	–	–
of aromatics	8	6	5	8	13	10	4

The impression was created that the decomposition of 2,3,3-trimethyl-1-butene with chromic catalysts is analogous to that discovered by one of authors [7] with an aluminum silicate catalyst, i.e. according to the scheme (I):



(I)

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* The method used for the experiments assured that the loss would not exceed 1%.

** See scheme (I)

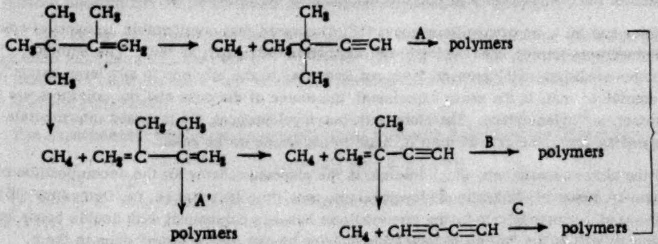
TABLE 2

Composition of liquid and gaseous products in experiments on the aromatization of 2,3,3-trimethyl-1-butene

Conditions and experimental results	Catalyst and experiment number						
	Chromic oxide on aluminum oxide			Chromic oxide			
	5	4	6	3	7	2	1
Composition of the liquid products (in % by weight):							
unsaturated hydrocarbons	76.1	–	79.3	90.0	74.4	85.0	93.0
aromatic hydrocarbons	20.9	50.7	7.5	10.0	24.6	15.0	5.0
saturated residue	3.0	–	12.2	0.0	0.8	0.0	2.0
Composition of the gaseous products (in % by volume):							
H_2	50	51.6	51.9	30.3	21.4	46.3	25.3
C_2H_4	1.4	2.8	2.8	1.8	6.4	3.0	2.7
C_3H_6	5.0	2.2	5.8	14.6	6.9	7.6	4.6
n-C_4H_8	2.2	1.8	2.1		3.8		
iso-C_4H_8	5.2	1.7	5.6	14.0	7.3	8.3	0.0
CH_4	26.6	23.6	16.5	38.8	35.7	34.9	67.4
C_2H_6	5.6	11.2	9.5		13.1		
C_3H_8	2.2	2.6	3.7		3.4		
ΣC_4H_{10}	1.3	1.6	1.7		1.3		

The partyl isomerized decomposition products, [C_4H_8, C_5H_{10}], in all probability in the presence of chromium catalysts [3] partly hydrogenate and partly dehydrogenate, which is fully possible thermodynamically [8].

The considerable formation of methane is explained by the large amount of demethanization of 2,3,3-trimethyl-1-butene followed by the polymerization of the products [see scheme(II)]. With this, a parallel dehydrogenation of the polymers during the polymerization occurs according to A,A', and B:



(II)

Table 1 shows the amount of coke formed (in % by weight) and amount of methane, expressed as moles per 100 moles of 2,3,3-trimethyl-1-butene used. If the demethanization proceeds according to the proposed outline, then the formation of one mole of methane must correspond to the following yield of coke, expressed in % by weight on the raw material used: A,A' – 0.835, B – 0.338, C – 0.170. Table 3 contains the yield of methane calculated on the yield of coke, as well as its true yield. The number of moles of hydrogen which is the difference between the sum: the hydrogen present plus that used for the hydrogenation of gaseous alkenes, and the hydrogen separating during the aromatization; i.e. the hydrogen obtained as a result of certain side dehydrogenations during the aromatization of a hundred moles of 2,3,3-trimethyl-1-butene is also given. This hydrogen is the product of the extensive dehydrogenation of polymers obtained by the polymerization and copolymerization of unsaturated compounds formed as a result of the demethanization of 2,3,3-trimethyl-1-butene. Some of the hydrogen and the coke could have been obtained from the dehydrogenation of isopentene, as well as from the intermediate products of the aromatization, and from the subsequent polymerization of the dehydrogenation products and the intermediate products of the aromatization.

TABLE 3

Results of a characteristic demethanization of 2,3,3-trimethyl-1-butene and side dehydrogenation reactions

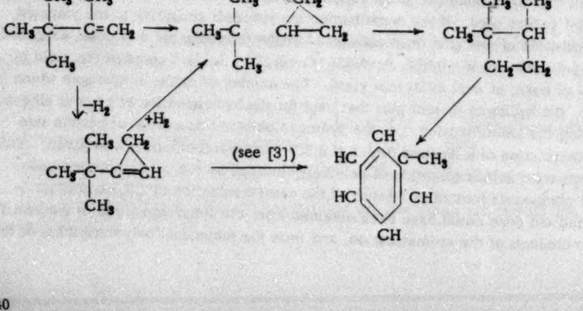
Yields of the products (in moles per 100 moles of 2,3,3-trimethyl-1-butene used)	Catalyst and experiment number						
	Chromic oxide on aluminum oxide			Chromic oxide			
	5	4	6	3	7	2	1
CH_4 calculated from scheme (II), A,A' on the yield of the coke	37	45	14	5	14	22	15
The same from scheme (II), B	92	110	35	13	35	54	37
The same from scheme (II), C	182	220	69	26	70	107	73
Actual yield of CH_4	57	67	19	–	57	>30	>29.6
Amount of H_2 from the side dehydrogenation	103	170	62	–	24	–	–

According to Table 3, the actual yield of methane in experiment 7 occupies an intermediate position between the yield calculated from schemes (II), B and (II), C; and for experiments 4,5,6 – from schemes (II), A,A' and (II), B. The amount of hydrogen from the dehydrogenation is considerably higher in experiments 4,5,6 than in experiment 7. The amount of hydrogen in experiment 6 can be considered somewhat low, as the hydrogen used for the formation of the saturated hydrocarbons was not counted (Table 2). The relatively small amount of hydrogen in experiment 7, i.e. where the demethanization of 2,3,3-trimethyl-1-butene proceeds mainly by means of schemes (II), B and (II), C according to the amount of methane and the comparatively large amount in experiments 4,5,6, i.e., where the reaction proceeds mainly by means of schemes (II), A,A' and (II), B, are considered to be proof of the conclusion that the main part of the coke is formed as a result of the polymerization of the demethanization products, and the dehydrogenation of these polymers. Judging from the results of Mattox and Grosse [14], the formation of any substantial amounts of coke as a result of the condensation of the aromatics under the conditions of these experiments, is excluded.

Under these experimental conditions, the extent of the aromatization varied between 4 to 13 moles per 100 moles of 2,3,3-trimethyl-1-butene used, while the concentration of 'aromatics' in the liquid products varied from 5-50% by weight. One of the authors [3] has proposed an outline for the aromatization of 2,3,3-trimethyl-1-butene which provides for the formation of tert.-butylcyclopropene as an intermediate product.

N. Ya. Demyanov and M. I. Doyarenko-Demyanova [15] discovered that considerable amounts of coke and cyclopropene polymers were formed when cyclopropene was passed over Al_2O_3 at 380°. The authors proposed that, under these conditions, cyclopropene "does not isomerize to the allylene to any large extent". Therefore, it can be considered that, in the above experiment, the source of the coke and the polymers was the cyclopropene or its isomer, methylacetylene. Therefore, tert.-butylcyclopropene, the proposed intermediate product, or the corresponding acetylene derived from it, must be the source of the coke.

The results of the above experiments, which resulted in the proposed scheme for the decomposition of 2,3,3-trimethyl-1-butene by means of 2,3,3-trimethylcyclobutane, recall the fact that N. Ya. Demyanov [16] considered the derivatives of cyclopropane to be the intermediates between compounds with double bonds and cyclobutane derivatives, as well as the "means of increasing the ring by one carbon atom" open to them.



(III)

As a result of the views of N. Ya. Demyanov, it can be supposed that tert.-butylcyclopropene is transformed into tert.-butylcyclopropane by means of the hydrogen from the dehydrogenations, which increases its ring to 2,2,3-trimethylcyclobutane. The transformation of this derivative of cyclobutane into toluene can be explained in several ways; for example, the opening of the ring to form methylhexane or methylhexene, and then, aromatization [see scheme (III)]. This scheme appears to be a workable hypothesis; the question of the mechanism of the aromatization of 2,3,3-trimethyl-1-butene and similar hydrocarbons needs further study.

It must be pointed out that, on relatively long contact with chromic oxide under approximately the same conditions (Experiments 4 and 7), the aromatization proceeded more extensively than with chromic oxide on aluminum oxide; on short contact time, the extent of the aromatization is equal (Experiments 3 and 5). The extent and the method of decomposition is the same, but the yield of coke is 3 times larger with chromic oxide on aluminum oxide (Table 1); the latter is particularly interesting because the duration of Experiment 7 was 50 minutes, and Experiment 4 – 23 minutes. In accordance with scheme(I) and Table 3, it can be concluded that, under the conditions of Experiment 7, the demethylation of the molecules of 2,3,3-trimethyl-1-butene with "chromic oxide" proceeds by means of equations B and C, i.e., almost completely, while the side dehydrogenations develop relatively slowly. With chromic oxide on aluminum oxide a large decrease in the contact time (Experiments 4 and 5) leads to a considerable decrease of the decomposition of 2,3,3-trimethyl-1-butene, as well as a reduction in the side dehydrogenations; thus, the extent of the demethanization decreases. Decrease of the temperature to 50°, has an effect analogous to the decrease of contact time, but the decrease in the extent of the decomposition, dehydrogenation, and demethanization is relatively much greater. (Experiments 5 and 6).

SUMMARY

Seven experiments on the aromatization of 2,3,3-trimethyl-1-butene with chromic oxide on aluminum oxide, and chromic oxide were conducted, which showed the following:

1) The aromatization of 2,3,3-trimethyl-1-butene proceeds to a relatively small extent; to 13% under the conditions used, but the fact of the aromatization itself shows that it is possible to aromatize hydrocarbons with four carbon atoms in the largest chain; the mechanism of this aromatization needs further investigating.

2) The main transformations of 2,3,3-trimethyl-1-butene with both catalysts appears to be its decomposition and demethanization, for which schemes (I) and (II) are proposed.

3) The secondary reactions are: a) dehydrogenation of the demethanization products and the decomposition of the intermediate products of the aromatization; b) the isomerization of isobutylene and the hydrogenation of the gaseous and liquid alkenes by means of the disproportionation of hydrogen.

4) The ability of chromium catalysts to effect the decomposition of 2,3,3-trimethyl-1-butene shows that they resemble aluminum silicate catalysts [7], in this way, and verify the conclusion made by one of the authors [3] that chromium catalysts can catalyze various transformation reactions of hydrocarbons in relation to fundamental reaction conditions.

The experimental part of the investigation was done with Zabulonov and Muzovskaya.

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XXXIX. α-OXIDES AND SYNTHESIS OF A SERIES OF THIOPHENE COMPOUNDS

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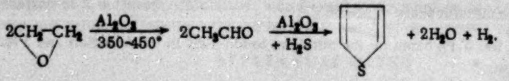
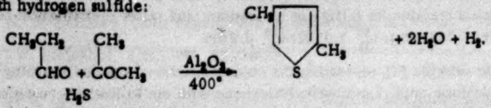
The reaction of ethylene oxide with hydrogen sulfide at 200°, in the presence of aluminum oxide, leads to six-membered saturated heterocycles with two heteroatoms in the 1,4-positions [1]; at higher temperatures (350-450°) – to thiophene [2,3]. The formation of thiophene is explained by the preliminary rearrangement of ethylene oxide into acetaldehyde, which then reacts with hydrogen sulfide by the well known reaction of A. E. Chichibabin [4]:



The reaction of ethylene oxide and hydrogen sulfide in contact with aluminum oxide at various temperatures was studied and it was found that the formation of thiophene already occurs at 300°; with increase in temperature the yield of thiophene increases and at 450° consists of 5.3% of the theoretical based on the ethylene oxide used in the reaction. According to the results of M. S. Malinovsky and B. N. Moriganov [2], the yield of thiophene at 450° is 6.5%.

It appeared interesting to see whether this reaction was general in character, i.e., can the homologs of ethylene oxide form homologs of thiophene under these conditions? In relation to propylene oxide it is known [5,6] that on contact with aluminum oxide it isomerizes to give a mixture of propionaldehyde and acetone.

In the present investigation it was shown that the reaction of propylene oxide with hydrogen sulfide in the presence of aluminum oxide at 400° leads to the formation of 2,4-dimethylthiophene. The formation of the latter can be explained only if the isomerization products of propylene oxide – acetone and propionaldehyde – reacted with hydrogen sulfide:



It was also found that 2,4-dimethylthiophene was formed even at 225° although in small amounts only. This appears to be a new fact upholding the rule found from the literature results that homologs of thiophene are formed more easily than thiophene itself [7].

EXPERIMENTAL

Reaction of ethylene oxide with hydrogen sulfide.

250°. 200 g of ethylene oxide was passed over Al_2O_3 in a stream of H_2S. 150 g of catalyzate was obtained (aqueous solution – 74.5 g; oil – 75.5 g). Upon the distillation of the aqueous and oily layer of the catalyzate were obtained: 1) 5.6 g of acetaldehyde [b.p. 20-22° (765 mm); m.p. of p-nitrophenylhydrazone – 128°]; 2) 3.4 g of 1,4-dioxane [b.p. 100-101° (765 mm); n_D^{20} 1.4216; d_4^{20} 1.0322]; 3) 2.5 g of a fraction corresponding in boiling point to 1,4-thioxane [b.p. 52-55° (13 mm); n_D^{20} 1.5052; d_4^{20} 0.9910]; 4) 2.9 g of a fraction corresponding in boiling point to 1,4-dithiane [b.p. 95-115° (50 mm)].

300°. 113 g of catalyzate was obtained from 170 g of ethylene oxide (aqueous solution – 57 g; oil 56 g). Upon distillation were isolated: 5.3 g of acetaldehyde (b.p. 20-22°) and 5.8 g of a fraction, b.p. 70-93°.

Upon the redistillation of the fraction with b.p. 70-93° over sodium, 2.4 g of a substance with b.p. 81-83°, n_D^{20} 1.5013, giving an indophene reaction with isatin and sulfuric acid, i.e. thiophene, was obtained. The α-chloromercurothiophene obtained from it melted at 182° after recrystallization from alcohol.

Literature results for α-chlormercurothiophene: m.p. 183° [8].

The yield of thiophene was 1.4% calculated on the ethylene oxide used in the reaction (4.3% of the weight of the oily layer of the catalyzate).

In addition, fractions corresponding in boiling point to the thioxane (2.4 g; b.p. 67-75° at 50 mm) and the dithiane (1.8 g; b.p. 100-120° at 50 mm).

350°. 110 g of catalyzate was obtained from 210 g of ethylene oxide (water –54 g; oil –56 g). Fractional distillation of the readily distillable substances of the aqueous and oily layers produced 5.5 g of a fraction with b.p. 80-90°, which, upon a subsequent redistillation over sodium, gave 4.1 g of thiophene; b.p. 82-84.5° (758 mm); n_D^{20} 1.5166; d_4^{20} 1.0690; melting point of the α-chloromercurothiophene (from alcohol) 183°.

The yield of the thiophene was 2.0%, based on the ethylene oxide used in the reaction and 7.2% of the weight of the oily layer.

400°. 92 g of catalyzate was obtained from 160 g of ethylene oxide (water –46 g, oil –46 g). 7.8 g of thiophene was obtained by fractional distillation over sodium; b.p. 82-84° (751 mm); n_D^{20} 1.5209, d_4^{20} 1.0620. Melting point of the α-chloromercurothiophene – 182-183°.

The yield of thiophene was 5.1% based on the ethylene oxide used in the reaction and 17% of the weight of the oily layer of the catalyzate.

450°. A turbid catalyzate was obtained from 220 g of ethylene oxide, which was distilled with super heated steam. The distillate was extracted with ether, and after the removal of the ether from the dried extract, the residue was fractionated. 11.2 g of thiophene with b.p. 83-84° (756 mm); n_D^{20} 1.5236; d_4^{20} 1.0490. Boiling point of the α-chloromecurothiophene –183°. The yield was 5.3% based on the ethylene oxide used.

Reaction of propylene oxide with hydrogen sulfide

400°. Propylene oxide (b.p. 34.5-35.0° at 753 mm) was passed over Al_2O_3 at a rate of 10 g per hour in a stream of H_2S. 200-250 g of propylene oxide was used in each experiment. 106 g of catalyzate was obtained from 212 g of the oxide (water –55 g, oil –51 g). On distillation of the oily fraction (dried with fused NaOH) from a flask with a column, the following fractions were obtained: (I) b.p. 100-125° –3.5 g; (II) b.p. 125-165° –23.5 g; (III) b.p. 165-250° –10.0 g; residue 12 g.

From Fraction II, upon redistillation through a column of 18 theoretical plates were separated: fraction with b.p. up to 136.5° – 3.5 g and a fraction with b.p. 136.5-139° (754 mm) –15.6 g. The latter had the odor of an aromatic hydrocarbon, did not give a reaction for sulfide or mercaptan, and, after redistillation once more over sodium had: b.p. 137.5-139.5° (750 mm); n_D^{20} 1.5102; d_4^{20} 0.9760.

After mercurating with mercuric chloride [6], separating the chloromercuro-compound, washing it with alcohol, and decomposing it with hydrochloric acid, 2,4-dimethylthiophene with the following constants was obtained: b.p. 138.5° (758 mm); n_D^{20} 1.5150; d_4^{20} 0.9899. The melting point of 5-chloromercuro-2,4-dimethylthiophene was 138°.

The literature results for 2,4-dimethylthiophene [9]: b.p. 138-139°; d_{20}^{20} 0.9956; melting point of 5-chloromercuro-2,4-dimethylthiophene [10] – 138-139°.

Found %: C 64.34, 64.38; H 7.74, 7.73; S 28.70, 28.67. C_6H_8S. Calculated %: C 64.23; H 7.20; S 28.56.

225°. 212 g of propylene oxide were used for the reaction. At the end of the reaction, a stream of nitrogen was passed in through a tube until the reaction products were completely removed and the temperature was increased 30°. 137 g of catalyzate was obtained (aqueous part – 53 g, oil – 84 g). The distillate of the water layer was dried and combined with the distillate of the oily catalyzate collected up to 190°.

Upon subsequent redistillation through a column of 18 theoretical plates, 4.3 g of a fraction with b.p. 47-135°, 9 g of a fraction with b.p. 135-141°, and 4.6 g of a fraction with b.p. 141-190° were obtained.

After redistillation of the fraction with b.p. 135-141° and distillation over sodium, 7.2 g of a fraction, with b.p. 138-140° (762 mm), n_D^{20} 1.5033 and d_4^{20} 0.9304, and which had an almost pure aromatic hydrocarbon odor, was obtained. The reaction for mercaptan was negative. The amount of sulfur (26.2%) was 2.35% lower than required for dimethylthiophene; the amount of carbon (66.06%) – 2.2% higher.

From the reaction, analytical results, as well as the constants of the fraction obtained, it can be concluded that it consists of 2,4-dimethylthiophene along with another substance – apparently, a hydrocarbon.

The chloromercuro compound was obtained by mercuration; which, after washing with and recrystallization from alcohol, melted at 138°.

On mixed melting point determination with mercurated 2,4-dimethylthiophene obtained in the previous experiment, no depression was observed, and the mixture melted at 138°.

2,4-Dimethylthiophene (1.6 g) was obtained upon the decomposition of the chloromercuro compound with hydrochloric acid which, after distillation over sodium, had the following constants: b.p. 137-137.5° (755 mm); n_D^{20} 1.5139; d_4^{20} 0.9912.

Found %: C 64.25, 64.23; H 7.41, 7.38; S 28.60, 28.56. C_6H_8S. Calculated %: C 64.23; H 7.20; S 28.56.

SUMMARY

It was shown that the reaction of propylene oxide with hydrogen sulfide over aluminum oxide at 400° leads to the formation of 2,4-dimethylthiophene, which can be explained by the initial isomerization of propylene oxide into acetone and propionaldehyde followed by the reaction of the mixture of the two with hydrogen sulfide.

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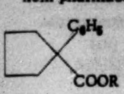
THE SYNTHESIS OF 1,1-PHENYLCYCLOPENTANE CARBOXYLIC AND 1,1-PHENYLCYCLOPENTANE THIOCARBOXYLIC ACIDS AND SEVERAL DERIVATIVES

K. V. Levshina and S. I. Sergievskaya

The synthesis of new spasmolytic substances of the type of alkylamino esters of disubstituted acetic esters occupies a considerable place in investigations of the past few years in the search for new medicinals. The changes in structure of the compounds synthesized for this purpose are extremely varied. Interesting modifications of the above type of spasmolytic substances appear to be alkylamino esters of alicyclic carboxylic acids, among which the esters of 1,1-phenylcyclopentane carboxylic acids (I) have attracted considerable attention from pharmacologists and clinicians because of certain peculiarities in its spasmolytic action.



(I)

Since esters of thiocarboxylic acids in many cases possess more clearly pronounced spasmolytic properties than those of the corresponding carboxylic acids, it appeared interesting to prepare several alkylamino esters of 1,1-phenylcyclopentane thiocarboxylic acid in order to investigate their pharmacological activity.

In order to prepare these compounds it was necessary to have 1,1-phenylcyclopentane thiocarboxylic acid as the starting material. According to the small number of papers in the literature [1], this acid is obtained by the condensation of 1,4-dibromobutane with benzyl cyanide in the presence of sodium amide followed by the saponification of the nitrile formed. The conditions for conducting each one of these reactions, as well as the properties of the 1,4-dibromobutane obtained, are varied. At the present time, 1,4-dibromobutane, for the most part, is obtained by the reaction of hydrogen bromide with tetrahydrofuran [2]. The authors repeated the methods given in the literature for conducting this reaction, and the most convenient method was shown to be the recommended prolonged heating of tetrahydrofuran with 48% hydrobromic acid. However, in this case the yield of 1,4-dibromobutane was inconsistant and lower than that reported in the literature. Considerably better results were obtained by adding sulfuric acid to the 48% hydrobromic acid and heating the tetrahydrofuran with a mixture of these acids. In this case 1,4-dibromobutane is obtained in a consistant and higher yield (70% of the theoretical). Toluene was used as the solvent for the condensation of 1,4-dibromobutane with benzyl cyanide instead of ether or liquid ammonia as given in the literature.

The saponification of 1,1-phenylcyclopentane nitrile was satisfactorily [1] effected by heating it with alcoholic alkali at atmospheric pressure, wherein 1,1-phenylcyclopentane carboxylic acid was obtained in a yield of 45.8 %. It is recommended that the heating be done in an autoclave at higher pressures; under these conditions phenylcyclopentane carboxylic acid is obtained in a yield of 95%.

The sodium salt and the acid chloride, whose constants were determined, were prepared from 1,1-phenylcyclopentane carboxylic acid.

The transformation of 1,1-phenylcyclopentane carboxylic acid to the corresponding thio-acid was effected by the action of an alcoholic solution of potassium hydrosulfide on the phenylcyclopentane carboxylic acid chloride. An excess of potassium hydrosulfide had to be used because in some cases a side reaction of the potassium salt of the thio-acid with the unreacted acid chloride to form the sulfide occurred.

1,1-Phenylcyclopentane thiocarboxylic acid is a crystalline, stable enough substance. In addition to its two alkylamino esters, the following common derivatives were obtained: potassium salt, disulfide, and ethyl ester.

EXPERIMENTAL

1,4-Dibromobutane. 1530 ml of 48% hydrobromic acid was placed in a 2-liter three-necked flask equipped with mechanical stirrer, reflux condenser, thermometer immersed in the liquid, and dropping funnel; in small portions with stirring, 307 ml of concentrated sulfuric acid was carefully added to it. 172 g of tetrahydrofuran was added stepwise from the dropping funnel to the mixture of the acids, and heating on the oil bath was begun; at 62-68° inside the flask, the liquid began to boil, and in relation to the development of the reaction, the boiling point of the liquid gradually increased; when it reached 100-105°, the heating was continued at this temperature for 20-23 hours.

Upon cooling, the reaction mixture was transferred to a separatory funnel, the lower layer containing the 1,4-dibromobutane, was separated, and the upper layer – the acids – was extracted with chloroform. The chloroform extracts were combined with the 1,4-dibromobutane, and the chloroform solution washed, first with a 10% sodium bicarbonate solution, and then with water. After drying with calcium chloride, the chloroform was removed, and the 1,4-dibromobutane vacuum distilled. B.p. 85-90° at 15 mm. Yield 365 g (70% of the theoretical).

1,1-Phenylcyclopentane carboxylic acid nitrile. 87 g sodium amide in 1300 ml of absolute toluene, was placed in a flask equipped with a stirrer, reflux condenser, thermometer immersed in the liquid, and dropping funnel; 109.3 g of benzyl cyanide was added in small portions with continuous stirring (so that the temperature did not rise above 35°) to the suspension. The reaction mixture, which turned red, was stirred for 5-10 min. until the temperature decreased to 20-25°, then 200 g of 1,4-dibromobutane was added from the dropping funnel at such a rate that the temperature of the reaction mixture did not exceed 50-55°. After the addition of the 1,4-dibromobutane, the flask with the reaction mixture was heated on the water bath to 90-92° inside the liquid for 24 hours, after this the reaction mass was cooled, and small portions of water were added until the sodium bromide formed dissolved completely; two layers formed. The toluene layer was separated in a separatory funnel, and the water layer was completely extracted with toluene. The combined toluene solutions were washed with water and then dried with sodium sulfate. The toluene was removed in vacuum; the residual nitrile was vacuum distilled two times. A fraction with b.p. 110-170° at 25-30 mm was collected during the first distillation. 140 g was obtained. On redistillation, a fraction with b.p. 145-160° at 25-30 mm was collected. 110 g (70% of the theoretical) was obtained.

1,1-Phenylcyclopentane carboxylic acid. 450 ml of a 20% solution of potassium hydroxide in methyl alcohol and 80 g of twice distilled 1,1-phenylcyclopentanecarboxylic acid nitrile were placed in a rotary autoclave, 1 liter capacity. The autoclave was closed, and the heating was begun with the rotation of the autoclave; the temperature inside the autoclave was gradually increased to 195-200°, and at this temperature, the agitation of the autoclave by means of its rotation was continued for 6 hours; the pressure inside the autoclave increased to 35-40 atm. After 6 hours the heating was stopped; when the autoclave cooled to room temperature, the ammonia was released, the autoclave was opened, the reaction mixture transferred to a Wurtz flask, and the alcohol was distilled off. The residue was dissolved in 500 ml of water and acidified with 240-250 ml of hydrochloric acid (1:1) until acid to Congo. The precipitated acid was filtered on a Buchner funnel, and washed with water; 84 g of impure 1,1-diphenylcyclopentane carboxylic acid with m.p. 157-158° (95% of the theoretical) was obtained. To obtain a sample for analysis, the 1,1-phenylcyclopentane carboxylic acid was recrystallized once from alcohol; m.p. 159°.

The sodium salt of 1,1-phenylcyclopentane carboxylic acid was obtained by treating 12 g of the acid with a saturated aqueous solution of 4.41 g of sodium bicarbonate. It was a colorless crystalline substance which crystallized from ethyl acetate in the form of needles. It melted above 220°.

0.3535 g substance: 0.1178 g Na_2SO_4. Found %: Na 10.84. $C_{12}H_{13}O_2Na$. Calculated %: Na 10.79.

1,1-Phenylcyclopentane carboxylic acid chloride. 50 g of 1,1-phenylcyclopentane carboxylic acid and 160 g of thionyl chloride were placed in a round bottomed flask equipped with a reflux condenser and heated to reflux on the water bath for 6 hours. The excess thionyl chloride was then removed, and the residue was vacuum distilled. A fraction with b.p. 149-150° at 20-23 mm was collected.

6.041 mg substance: 4.144 mg AgCl. Found %: Cl 16.97. $C_{12}H_{13}OCl$. Calculated %: Cl 17.02.

Potassium salt of 1,1-phenylcyclopentanethiocarboxylic acid. A solution of potassium hydrosulfide, obtained by saturating a solution of 25.3 g of potassium hydroxide in 14 ml of water and 447 ml of ethyl alcohol with hydrogen sulfide at −5° (until a weight increase of 22.4 g), was placed in a three-necked flask equipped with a stirrer, thermometer, reflux condenser, and dropping funnel. A solution of 44.7 g of 1,1-phenylcyclopentane carboxylic acid chloride in 350 ml of dry benzene was added stepwise at 5° to the above solution of potassium hydrosulfide. The mixture was stirred at this temperature for 20-30 min., filtered, and the solvents removed from the filtrate in vacuum (alcohol, benzene, water). The oily residue crystallized when absolute ether was added to it. After washing the crystalline substance with ether and its recrystallization from ethyl acetate, an almost colorless substance, with m.p. 166-167, readily soluble in water, was obtained. Yield 65-70% of the theoretical.

0.1061 g substance: 0.0998 g $BaSO_4$. 0.2157 g substance: 0.2050 g $BaSO_4$. Found %: S 12.91, 13.05. $C_{12}H_{13}OSK$. Calculated %: S 13.1.

1,1-Phenylcyclopentane thiocarboxylic acid. The potassium salt of 1,1-phenylcyclopentane thiocarboxylic acid was dissolved in water, the aqueous solution was filtered, and the free 1,1-phenylcyclopentane thiocarboxylic acid separated on the addition of 10% hydrochloric acid; after recrystallization from alcohol, colorless needles with m.p. 43-44°, soluble in alcohol, ethyl acetate, ether, and insoluble in water were obtained. Yield – 85% of the theoretical based on the potassium salt used.

4.017 mg substance: 10.280 mg CO_2; 2.418 mg H_2O. 0.2026 g substance: 0.2260 g $BaSO_4$. Found %: C 69.79; H 6.73; S 15.31. $C_{12}H_{14}OS$. Calculated %: C 69.65; H 6.76; S 15.4.

Sulfide of 1,1-phenylcyclopentane thiocarboxylic acid $C_5H_8(C_6H_5)CO{-}S{-}CO(C_6H_5)C_5H_8$. A solution of potassium hydrosulfide, prepared by saturating a solution of 5.5 g of potassium hydroxide in 100 ml of alcohol and 3 ml of water with hydrogen sulfide at –5° until a 5-6 g weight increase, was placed in a three-necked flask equipped with a stirrer, thermometer, reflux condenser, and dropping funnel. 11 g of 1,1-phenylcyclopentane carboxylic acid chloride in 30 ml of benzene was added stepwise to the above potassium hydrosulfide solution and the stirring at –5° was continued for 30 min. more. The precipitate, consisting of potassium chloride and the sulfide of the thioacid, was filtered and carefully washed free of the potassium chloride with water. The part insoluble in water was recrystallized from ethyl acetate. The colorless, shiny, crystals with m.p. 113-114° were insoluble in water and ether, and soluble in alcohol.

3.800 mg substance: 10.658 mg CO_2; 2.380 mg H_2O. 0.2290 g substance: 0.1432 g $BaSO_4$. Found %: C 76.49; H 7.00; S 8.58. $C_{24}H_{26}O_2S$. Calculated %: C 76.2; H 6.87; S 8.52.

Disulfide of 1,1-phenylcyclopentane thiocarboxylic acid. 3 g of 1,1-phenylcyclopentane thiocarboxylic acid was dissolved in the cold in 90 ml of ethyl alcohol. Concentrated hydrochloric acid was added stepwise to the above solution until acid to Congo, and an alcoholic solution of $FeCl_3$ was added stepwise. An almost colorless precipitate formed in the reaction mixture on rubbing with a rod, which was filtered, washed with water, and recrystallized from a mixture of ethyl acetate and alcohol. 1.5 g of a disulfide with m.p. 82-83.5° was obtained in the form of colorless crystals insoluble in water and soluble in alcohol and acetone.

3.079 mg substance: 7.934 mg CO_2; 1.670 mg H_2O. 3.431 mg substance: 8.858 mg CO_2; 1.936 mg H_2O. 0.2239 g substance: 0.2540 g $BaSO_4$. 0.2120 g substance: 0.2427 g $BaSO_4$. Found %: C 70.28, 70.41; H 6.07, 6.31; S 15.57, 15.71. $C_{24}H_{26}O_2S_2$. Calculated %: C 70.24; H 6.34; S 15.60.

Ethyl ester of 1,1-phenylcyclopentane thiocarboxylic acid. 8 g of the potassium salt of 1,1-phenylcyclopentane thiocarboxylic acid, 22.5 g of ethyl iodide, and 150 ml of absolute alcohol were placed in a round-bottomed flask equipped with a reflux condenser. The mixture was heated on the water bath to the boiling temperature of alcohol for 5 hours. The precipitated potassium iodide was filtered, and the alcohol and excess ethyl iodide were removed. The residue was dissolved in ether, the ether solution was washed with water, dried with sodium sulfate, and the ether removed. The residue was vacuum distilled. The ethyl ester of the thioacid was a thick, colorless liquid with b.p. 134° at 3-4 mm.

4.980 mg substance: 13.043 mg CO_2; 3.311 mg H_2O. 0.2302 g substance: 0.2301 g $BaSO_4$. Found %: C 71.43; H 7.44; S 13.72. $C_{14}H_{18}OS$. Calculated %: C 71.79; H 7.68; S 13.67.

Hydrochloride of the diethylaminoethyl ester of 1,1-phenylcyclopentane thiocarboxylic acid. 1.35 g of the potassium salt of 1,1-phenylcyclopentane thiocarboxylic acid and 40 ml of absolute ethyl alcohol were placed in a round-bottomed flask connected with a reflux condenser. 0.8 g of freshly distilled diethylaminoethyl chloride was added to the solution. The mixture obtained was heated on the water bath for 4 hours at 45° (bath temperature); at the end of the reaction, the potassium chloride precipitate was separated and the alcohol vacuum distilled. The residual oily substance was heated in vacuum on the water bath for 1 hour to remove the traces of unreacted diethylaminoethyl chloride, and then dissolved in ether. The solution was washed with water and dried with anhydrous sodium sulfate, filtered, and an ether solution of hydrogen chloride was added to the filtrate until acid to Congo. An almost colorless substance separated, which, after recrystallization from ethyl acetate, melted at 137-137.5°.

The hydrochloride of diethylaminoethyl thioester is readily soluble in water, alcohol, and acetone, and difficultly soluble in ethyl acetate, benzene, and insoluble in ether.

4.049 mg substance: 9.423 mg CO_2; 3.010 mg H_2O. 3.018 mg substance: 7.008 mg CO_2; 2.287 mg H_2O. 5.905 mg substance: 1.54 ml 0.01 N H_2SO_4. 6.187 mg substance: 1.80 ml 0.01 N H_2SO_4. 0.2170 g substance: 0.1483 g $BaSO_4$. 0.1802 g substance: 0.1228 g $BaSO_4$. 6.052 mg substance: 2.633 mg AgCl. 4.690 mg substance: 2.000 mg AgCl Found %: C 63.16, 63.33; H 8.28, 8.29; N 4.13, 4.07; S 9.38, 9.35; Cl 10.76, 10.55. $C_{18}H_{27}OSN \cdot HCl$. Calculated %: C 63.25; H 8.19; N 4.10; S 9.37; Cl 10.40.

Hydrochloride of the diethylaminopropyl ester of 1,1-phenylcyclopentane thiocarboxylic acid. 7.5 g of the potassium salt of 1,1-phenylcyclopentane thiocarboxylic acid, 7 g of diethylaminopropyl chloride hydrochloride, and 200 ml of absolute alcohol were placed in a round-bottomed flask connected with a reflux condenser. The mixture was heated to the boiling of the alcohol on the water bath for 3 hours. The precipitated potassium chloride was filtered, and the alcohol was removed from the filtrate in vacuum. The residue, the hydrochloride of the alkylamino thioester, was purified by converting it to the free base. A sodium bicarbonate solution was added to the hydrochloride, and the oil which separated, was extracted with ether. The ether solution of the alkylamino base was washed with water, dried with potassium carbonate, and the ether removed. The residual oil-like substance was heated on the water bath in vacuum for 1 hour in order to remove the traces of unreacted diethylaminopropyl chloride, and then dissolved in absolute ether. The ether solution was filtered, and an ether solution of hydrogen chloride was added to the filtrate, whereupon the hydrochloride of the diethylaminopropyl ester of 1,1-phenylcyclopentane thiocarboxylic acid separated which, after recrystallization from a mixture of alcohol and ethyl acetate, melted at 132-133°.

The hydrochloride of the alkylamino ester is readily soluble in water and in alcohol, poorly soluble in ethyl acetate, and insoluble in ether.

3.471 mg substance: 8.157 mg CO_2; 2.621 mg H_2O. 3.860 mg substance: 9.122 mg CO_2; 2.926 mg H_2O. 7.595 mg substance: 0.270 ml N_2 (23.5°, 733.0 mm). 6.675 mg substance: 0.249 ml N_2 (21.5°, 734.0 mm). 0.1347 g substance: 0.0880 g $BaSO_4$. 0.1638 g substance: 0.1086 g $BaSO_4$. Found %: C 64.09, 64.45; H 8.45, 8.48; N 3.96, 4.17; S 8.97, 9.10. $C_{19}H_{29}ONS \cdot HCl$. Calculated %: C 64.13; H 8.43; N 3.93; S 9.00.

SUMMARY

1. Improved methods for the preparation of 1,4-dibromobutane, 1,1-phenylcyclopentane carboxylic acid, and its acid chloride are reported.

2. 1,1-Phenylcyclopentane thiocarboxylic acid, its usual derivatives, and some dialkylaminoalkyl esters were prepared.

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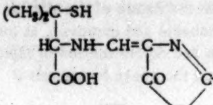
THIAZOLIDINE-4-CARBOXYLIC ACID AND ITS DERIVATIVES

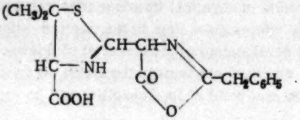
IV. INVESTIGATION OF THE PRODUCTS OF THE CONDENSATION OF CYSTEINE AND 4-ETHOXYMETHYLEN-2-PHENYL-5-OXAZOLONE

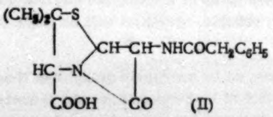
L. T. Strukov

Certain investigators, concerned with the solution of problems on the preparation of synthetic penicillin, have looked upon the thiazolidine-oxazolone structure (I) [1] as the intermediate compound in the process of formation of the antibiotic. For this reason many unsuccessful attempts were made to prepare compound (I).

Carpenter, Turner, and du Vigneau [2] prepared benzylpenicillin by heating d-benzylpenicillic acid (III) in pyridine in the presence of pyridine hydrochloride. On this basis, the authors considered that benzyl penicillic acid was the intermediate compound in the process of formation of penicillin.


(III)


(I)

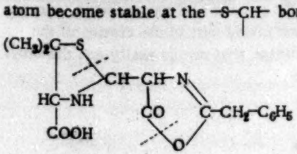

(II)

The insignificantly small yield of penicillin (0.1%) cannot serve as a conclusive argument in favor of this theory; however, at a certain step, the transformation of d-benzylpenicillic acid (III) into thiazolidine-oxazolone (I), and then into penicillin (II) must be considered. In this case the closing of the thiazolidine ring can occur by means of the reaction of the mercapto group with the ethylene-imine group of d-benzylpenicillenic acid.

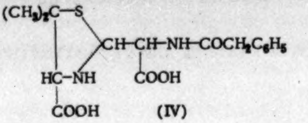
The transformation of d-benzyl penicillenic acid into benzyl penicillin appears to be a two-stage process, and for this reason, it is difficult to understand the reason for the obstacle to the formation of penicillin in more significant amounts. It is possible that the above hypothesis on the course of the chemical process is incorrect.

On the other hand, the wealth of experimental material from the study of saturated and unsaturated oxazolones [3] makes possible the construction of a more or less probable hypothesis that the thiazolidine-oxazolone structure (I) must be more stable than the thiazolidine-β-lactam structure of penicillin, and that it is possible to achieve a rearrangement with the opening of the oxazolone and the closing of the β-lactam ring, as a result of the mobility of the hydrogen of the imino group of the thiazolidine group. Apparently the investigators had this hypothetical possibility in mind during attempts to solve the problem of the synthesis of penicillin.

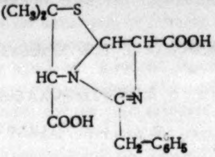
Penicillin may be looked upon as an unusually acylated thiazolidine compound with the properties of an N-acylthiazolidine-4-carboxylic acid [4]. In contrast to thiazolidine compounds, those acylated on the nitrogen atom become stable at the $-S-\underset{|}{C}H-$ bonds (1,2-position on the thiazolidine ring). Therefore, the lability of the β-lactam ring of penicillin stabilizes its thiazolidine ring, and for this reason, penicillin is considerably more stable than its thiazolidine-oxazolone structure with two labile bonds (Ia).


(Ia)

For this reason it is very possible that the thiazolidine-oxazolone structure, which arises, will tend to be stabilized. Because of this, as a result of the internal rearrangement, penicillin (II) can be formed; the split of the sulfur-carbon bond leads to penicillinic acid (III), while the rupture of the carbonyl – oxygen – to penicilloinic acid (IV) or its derivatives, and finally, to penillic acid (V):



(IV)



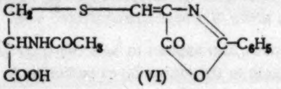
(V)

On this basis it must be considered that the thiazolidine-oxazolone structure is present at the moment of formation, and one should not search for the proof of the above theory in aimless attempts to isolate this compound. However, this view must not serve as an obstacle to attempts to synthesize penicillin by means of the thiazolidine-oxazolone structure.

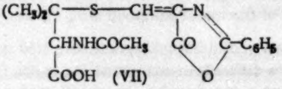
Organic chemistry, upon the study of biological reactions, enters into a new zone of its development when it encounters reactions occurring in the living organism, where newly formed structural systems rapidly change their structure; therefore, the course of chemical transformation can only be judged from the nature of the starting and final materials. All of the intermediate steps in the transformation will remain probable and unproven, as long as there are no means in the development of the processes of science for the isolation and determination of rapidly forming and disappearing structural elements in the living organism. For this reason the above hypothesis is considered satisfactory, and new proof of its probability will be sought.

It is possible that d-benzylpenicillinic acid (III) can change into the thiazolidine-oxazolone (I). For this to occur, it is necessary that the hydrogen of the mercaptan group be mobile, the ethylene-imino group be able to add to the mercaptan group, and that this be sterically possible. Attempts will be made to show these unusual conditions in model compounds.

N-Acetylcysteine has a more mobile hydrogen atom on its mercaptan group than N-acetylpenicillamine. This conclusion was made by comparing the rate of reaction of N-acetylcysteine and N-acetylpenicillamine with 4-ethoxymethylen-2-phenyl-5-oxazolone in pyridine, where it was shown that N-acetylcysteine reacts even at 0-10° while N-acetylpenicillamine reacts only at 50-55°. S-(2-phenyl-5-oxazolonylmethylen-4)-N-acetylcysteine (VI) and S-(2-phenyl-5-oxazolonylmethylen-4)-N-acetylpenicillamine (VII) are formed.



(VI)

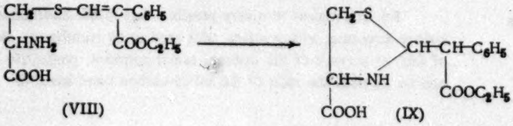


(VII)

Therefore, it will be more convenient to use N-acetylcysteine for the model reactions.

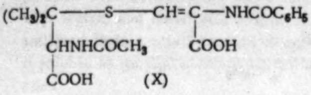
If the theory on the transformation of d-benzylpenicillenic acid to the thiazolidine-oxazolone (I) is true, then, according to the known step, it must be true that N-acetylcysteine can also react with 4-aminomethylen-2-phenyl-5-oxazolone. It seemed that compound (VI) could be obtained in this manner. The reaction was effected in dry pyridine in the presence of pyridine hydrochloride in order to avoid the rupture of the oxazolone ring and bind up the ammonia that separates in the form of ammonium chloride. In spite of prolonged heating, compound (VI) could not be obtained. This may lead to the proposal that the transformation of d-benzylpenicillenic acid into thiazolidine-oxazolone is scarcely probable.

In communication (II) [5] it was shown that β-S-(α-phenyl-α-carbethoxy)-ethylenecysteine (VIII) is easily formed by the action of methoxymethylen-phenylacetic ester on cysteine in the presence of concentrated hydrochloric acid. The hydrochloric acid protects the amino group of cysteine from taking part in the closing of the thiazolidine ring. When the protection is removed, the closing of the thiazolidine ring occurs easily and the ethyl ester of (4-carboxythiazolidyl-2)-phenylacetic acid (IX) is formed:



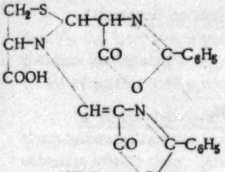
(VIII) (IX)

This reaction presented new possibilities for the preparation of thiazolidine-oxazolones; for this reason an attempt was made to prepare S-(2-phenyl-5-oxazolonylmethylen-4)-cysteine (XII) in order to then obtain the thiazolidene-oxazolone (XIII), and subsequently, desdim thylphenylpenicillin. However, compound (XII) could not be obtained by the condensation of cysteine hydrochloride with 4-ethoxymethylen-2-phenyl-5-oxazolone since a precipitate of 4-hydroxymethylen-2-phenyl-5-oxazolone formed, and the reaction did not progress any futther. In such a reaction, it was found useless to remove the acetyl group of compound (VII) since the oxazolone ring ruptured first, as can be observed from the disappearance of the color, the formation of the dicarboxylic acid, and the absence of iodine-oxidizing ability in the compound. In this case the formation of α-benzoyl- β-S-(N-acetylpenicillamine)-acrylic acid (X) occurs.



$(CH_3)_2C(CH(NHCOCH_3)COOH)-S-CH{=}C(COOH)-NHCOC_6H_5$ (X)

The extremely great reactivity of the mercaptan and the amino groups of cysteine was used to prepare S,N-disubstituted cysteines. For example, the pyridine salt of S,N-di-(2-phenyl-5-oxazolonylmethylen-4) cysteine was formed by the condensation of cysteine hydrochloride with 4-ethoxymethylen-2-phenyl-5-oxazolone in pyridine; the free acid (XI) was then isolated. Structure (XI) was doubted for some time since a suggestion was made that the thiazolidene-oxazolone (XIII), and an unusually acylated 4-ethoxymethylen-2-phenyl-5-oxazolone (XI a) were formed in this case.



(XIa)

This doubt was removed by the study of the ultraviolet absorption spectra prepared by Yu. N. Shenker in the physico-chemical laboratory of the authors' institute. Upon the study of the spectra of S-(2-phenyl-5-oxazolonylmethylenyl-4)-N-acetylcysteine and S,N-di-(2-phenyl-5-oxazolonylmethylenyl-4)cysteine (XI), a maximum at 3600 A was obtained for the first, and two maxima, at 3600 and 3450 A, for the second; these verified the proposed structure (XI). If this compound had the structure (XIa), then the first maximum, characteristic for the mercaptomethylenyl-2-phenyl-5-oxazolonyl groups, would not have been found.

Upon treating S,N-di-(2-phenyl-5-oxazolonylmethylenyl-4)cysteine with a 25% solution of ammonia for 5 minutes, 1 mole of 4-aminomethylenyl-2-phenyl-5-oxazolone precipitated quantitatively. The amide of desdimethylphenylpenicilloinic acid (XIV) was isolated in a yield of 85% of the theoretical from the mother liquor.

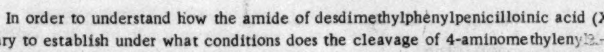
In order to understand how the amide of desdimethylphenylpenicilloinic acid (XIV) was formed, it was necessary to establish under what conditions does the cleavage of 4-aminomethylenyl-2-phenyl-5-oxazolone into compound (XI) occur. When 4-aminomethylenyl-2-phenyl-5-oxazolone is heated with aniline, ammonia is evolved and 4-anilinomethylenyl-phenyl-5-oxazolone is formed. Therefore the amino group can take place in exchange reactions. More characteristic was the treatment of compound (VI) with aqueous ammonia, with which 4-aminomethylen-2-phenyl-5-oxazolone could not be isolated.

From this it could be suggested that, by the action of ammonia on compound (XI), the first intermediate compound could have been S-(2-phenyl-5-oxazolonylmethylenyl-4)cysteine (XII) which is transformed into the thiazolidine-oxazolone (XIII) and then, into the α-amide of desdimethylphenylpenicilloinic acid (XIV).

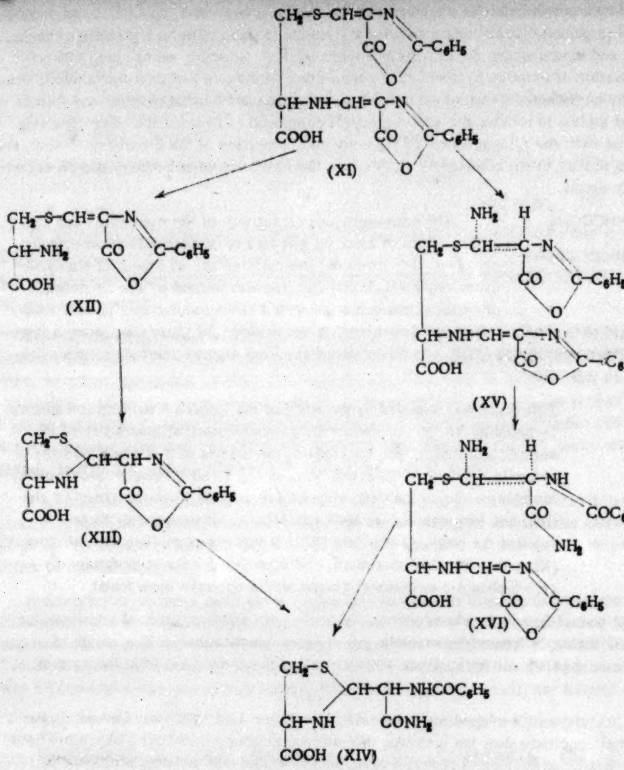
From the above step it is clear that another representation of the course of this reaction is: the ammonia momentarily adds to the ethylene-sulfide of compound (XI) to form the saturated oxazolone system (XV) which readily rearranges into the amide (XVI). The cleavage of 4-aminomethylenyl-2-phenyl-5-oxazolone and ammonia occurs simultaneously, after which the thiazolidene ring closes. It is possible that there is a somewhat different sequence of chemical transformations, but the final product of the reaction does not differ because of this.

The course of the reaction is shown in the following scheme: (see top of next page)

The structure of the α-amide of desdimethylphenylpenicilloinic acid (XIV) was determined by its synthesis from cysteine hydrochloride and diethoxymethylhippuric amide (XVII) which is readily formed by the action of aqueous-alcoholic ammonia on methyl diethoxymethylhippurate (XVII):



$$\underset{\text{(XVIII)}}{(C_2H_5O)_2CH-CH(COOCH_3)-NHCOC_6H_5} \longrightarrow \underset{\text{(XVII)}}{(C_2H_5O)_2CH-CH(CONH_2)-NH-COC_6H_5}$$



The amide of desdimethylphenylpenicilloinic acid (XIV) prepared by the above method, has the same melting point, does not give a depression, and crystallizes with the same crystalline system. The dinitrophenylhydrazone of formylhippuric amide was obtained from compound (XIV) upon its decomposition into cysteine and formylhippuric amide, as well as from diethoxymethylhippuric amide (XVII). Both of the dinitrophenylhydrazones formed in the above manner did not give a depression in melting point.

EXPERIMENTAL

1-S-(2-Phenyl-5-oxazolonylmethylenyl-4)-N-acetylcysteine. 0.4 g of N-acetyl-1-cysteine and 0.5 g of 4-ethoxymethylenyl-2-phenyl-5-oxazolone were dissolved in 2 ml of dry pyridine. A crystalline precipitate began to form rapidly, and after one hour, the mass crystallized. A small amount of ether was added, the precipitate filtered, washed with ether, and then recrystallized from pyridine with ether added to cloudiness. Microcrystalline, pale yellow needles clustered into spherical crystals, m.p. 123°.

8.454 mg substance: 5.94 ml 0.01 N H_2SO_4 (Kjeldahl). Found %: N 9.84. $C_{15}H_{14}O_5N_2S \cdot C_5H_5N$. Calculated %: N 10.17.

The compound obtained did not contain a free mercaptan group (negative nitroprusside reaction). When the substance was treated with a 10% sodium hydroxide solution, the odor of pyridine formed.

0.2 g of the substance was treated with 1 ml of 2 N hydrochloric in the presence 100 ml of ether. The ether solution was separated, dried with sodium sulfate, and the ether removed. The residue was recrystallized from 2 ml of acetone containing 3 ml of ether. Spherical, pale yellow crystals with m.p. 166-168° (decomp.). They are soluble in hot water and acetone, and poorly soluble in ether and ethyl acetate.

8.214 mg substance: 4.80 ml 0.01 N H_2SO_4. Found %: N 8.18. $C_{15}H_{14}O_5N_2S$. Calculated %: N 8.38.

In contrast to thiazolidine compounds, it does not react with 0.1 N iodine solution and does not form a precipitate of 4-aminomethylene-2-phenyl-5-oxazolone on treatment with 25% ammonia solution.

S-(2-Phenyl-5-oxazolonylmethylene-4)-N-acetylpenicillamine (VII). 1.5 g of 4-ethoxymethylene-2-phenyl-5-oxazolone, 1.35 g of N-acetylpenicillamine, and 5 ml of dry pyridine were heated for 5 hours at 50-55°. The reaction mixture was transferred with 300 ml of ether to a separatory funnel, and the ether solution was treated with 10% sulfuric acid. The ether solution was washed with water, and then was shaken with 15 ml of a 5% sodium bicarbonate solution. After the separation of the ether layer, 1 liter of ether, and a 10% sulfuric acid solution were added to the water solution. The substance, which separated, dissolved in the ether, was washed with water, and dried with magnesium sulfate. After the removal of the ether, the yellow residue was recrystallized from a small amount of acetone. Pale yellow needles with m.p. 176-177° (decomp.). The substance is soluble in methyl alcohol, chloroform, dioxane, and ethyl acetate, poorly – in acetone and very poorly – in ether.

6.425 mg substance: 0.431 ml N_2 (20°, 730 mm). 3.990 mg substance: 0.284 ml N_2 (25°, 731 mm). Found %: N 7.51, 7.85. $C_{17}H_{18}O_5N_2S$. Calculated %: N 7.73.

Like compound (VI) it does not react with 0.1 N iodine solution and 25% ammonia solution.

Attempted condensation of N-acetylcysteine with 4-aminomethylene-2-phenyl-5-oxazolone. Upon heating 0.4 g of N-acetyl-l-cysteine with 0.5 g of 4-aminomethylene-2-phenyl-5-oxazolone in 6 ml of dry pyridine containing 0.2 g of hydrogen chloride for 10 hours at 50-55°, and diluting the reaction mixture with 50 ml of water, 0.48 g of 4-aminomethylene-2-phenyl-5-oxazolone with m.p. 214-215° was recovered.

α-Benzoyl-β-S-(acetylpenicillamine)-acrylic acid. 0.6 g of S-(2-phenyl-5-oxazolonylmethylene-4)-N-acetylpenicillamine was dissolved in 2 ml of concentrated hydrochloric acid. The yellow solution became colorless after 1 hour. After 6 hours the hydrochloric acid was removed in a vacuum desiccator. The residual solid, white substance was powdered and dried for a long period over sulfuric acid and sodium hydroxide in a vacuum desiccator. The substance was very soluble in water and methyl alcohol, and soluble in acetone and dioxane.

0.0955 g substance: 5.1 ml 0.1 N NaOH. Found %: COOH. 24.03. $C_{15}H_{18}O_2N_2S(COOH)_2$. Calculated %: COOH 23.68.

4-Anilinomethylene-2-phenyl-5-oxazolone. 0.7 g of 4-aminomethylene-2-phenyl-5-oxazolone, 0.4 g of aniline, and 2 ml of dry pyridine were heated for 25 hours at 80-90°; ammonia separated. The reaction mixture was added stepwise to 20 ml of 10% sulfuric acid, and a thick yellow oil separated. Yellow crystals with m.p. 154-155° were formed on treatment with methyl alcohol. They were identical with those reported in the literature [6].

S,N-Di-(2-phenyl-5-oxazolonylmethylene-4-)-cysteine. 2.8 g of 4-ethoxymethylene-2-phenyl-5-oxazolone and 1 g of dl-cysteine hydrochloride were dissolved by shaking in 15 ml of dry pyridine. The yellow crystalline precipitate, which formed in a few hours, was filtered, and washed with pyridine and then with ether. It was recrystallized from pyridine and dried in a vacuum desiccator over sulfuric acid. Yellow needles with m.p. 155-156° (decomp.).

4.723 mg substance: 0.421 ml N_2 (23.5°, 734 mm). 0.1824 g substance: 0.0819 g $BaSO_4$. Found %: N 9.91; S 6.16. $C_{23}H_{17}O_6N_3S \cdot C_5H_5N$. Calculated %: N 10.33; S 5.91.

The pyridine salt is poorly soluble in hot water, soluble in alcohol and acetone, and insoluble in ether and benzene. When treated with 10% sodium hydroxide solution, the odor of pyridine formed.

0.5 g of the pyridine salt (XI) was shaken with 250 ml of ether in the presence of 2 ml of 2 N hydrochloric acid. The ether solution was washed with water, dried with magnesium sulfate, and the ether removed to a 20 ml volume. A yellow precipitate of spherical crystals, poorly soluble in benzene and ether, separated; m.p. 165-167° (decomp.).

5.587 mg substance: 0.451 ml N_2 (23°, 723 mm). 4.580 mg substance: 0.367 ml N_2 (23.5°, 723 mm). Found %: N 8.86, 8.78. $C_{23}H_{17}O_6N_3S$. Calculated %: N 9.07.

Decomposition of the pyridine salt (XI) with ammonia. 3 g of the pyridine salt (XI) was dissolved in 30 ml of 25% ammonia solution and left to stand for 3 hours. The precipitate, which separated, was filtered, washed with water, and dried; weight 1.087 g. After recrystallization from methyl alcohol, m.p. 215-216° (decomp.). It did not give a depression in melting point with 4-aminomethylene-2-phenyl-5-oxazolone.

The water solution was evaporated to dryness in vacuum at 40-50°, the residue was dissolved in 15 ml of water, filtered, and after cooling to 0°, acidified with 10% hydrochloric acid to a weakly acid reaction on Congo. The precipitate was filtered and washed with water; weight 1.3 g. The substance was purified by transforming it to the sodium salt and reprecipitating with hydrochloric acid. Spherical crystals with m.p. 186-187° (decomp.), soluble in warm water, and poorly soluble in most organic solvents.

4.989 mg substance: 0.592 ml N_2 (19.5°, 742 mm). 0.2016 g substance: 6.5 ml 0.1 N NaOH. Found %: N 13.52; COOH 14.51. $C_{13}H_{15}O_4N_3S$. Calculated %: N 13.59; COOH 14.56.

0.2016 g of the substance in 10 ml water was titrated with 6.5 ml of 0.1 N sodium hydroxide solution to phenolphthalein, the solution acidified with a drop of hydrochloric acid, and titrated with 6.6 ml of 0.1 N iodine solution. The solution obtained readily reduced silver. A solution of diphenylhydrazine hydrochloride was added to the above solution. A microcrystalline precipitate with m.p. 207-208° (decomp.) formed. It did not give a depression in melting point with formylhippuric amide dinitrophenylhydrazone (for its preparation see below).

Diethoxymethylhippuric amide (XVII). 5 g of methyl diethoxymethylhippurate was dissolved in 30 ml of alcohol and 50 ml of 25% ammonia solution was added. The voluminous crystalline precipitate, which separated after 3 days, was filtered and recrystallized from methanol. Thin, colorless needles with m.p. 168-169°.

5.720 mg substance: 0.520 ml N_2 (22°, 738 mm). 6.820 mg substance: 0.617 ml N_2 (24.5°, 744° mm). Found %: N 10.22, 10.18. $C_{14}H_{20}O_4N_2$. Calculated %: N 9.99.

0.9 g of the substance was dissolved in 5 ml of concentrated hydrochloric acid and left to stand for 1 hour at 0°; 1 ml of the solution was diluted with 10 ml of water, and a solution of dinitrophenyl hydrazine hydrochloride was added. A microcrystalline precipitate of formylhippuric amide phenylhydrazone with m.p. 208-209° (decomp) separated.

Amide of desdimethylphenylpenicilloinic acid (XIV). 0.5 g dl-cysteine hydrochloride, 0.8 g of diethoxymethylhippuric amide were heated for 5 hours at 70° in 15 ml of 50% ethyl alcohol; a test for the mercaptan group by means of nitroprusside reaction almost completely disappeared. The next day the precipitate was filtered and purified by reprecipitating a solution of the ammonium salt with hydrochloric acid. White, spherical crystals with m.p. 186° (decomp).,

4.515 mg substance: 0.537 ml N_2 (21.5°, 746 mm). 4.900 mg substance: 0.593 ml N_2 (21°, 740 mm). Found %: N 13.57, 13.78. $C_{13}H_{15}O_4N_3S$. Calculated %: N 13.59.

SUMMARY

It was shown that 4-aminomethylene-2-benzyl-5-oxazolone and the α-amide of desdimethylphenylpenicilloinic acid were formed by the action of aqueous ammonia on S,N-di-(2-phenyl-5-oxazolonylmethylene-4)-cysteine.

A suggestion was made that the reactions forming the α-amide of desdimethylphenylpenicilloinic acids occur with S-(2-phenyl-5-oxazolonylmethylene-4)-cysteine and 2'-(2-phenyl-5-oxazolonyl-4)-thiazolidine-4-carboxylic acid as intermediate compounds.

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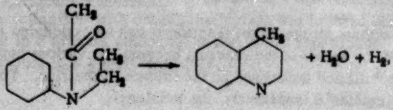
* See Consultants Bureau English translation, p. 1077.

DERIVATIVES OF QUINOLINE

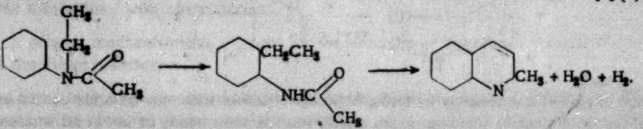
IX. ON THE MECHANISM OF THE PICTET REACTION

B. I. Ardashev and B. A. Tertov

Attempts to cyclize various organic compounds of apparently similar structure into γ-quinoline derivatives often lead to α-substituted ones. Several examples are: The anils of crotonaldehyde and cinnamaldehyde, upon distillation in the presence of mineral acids, form quinaldine [1], and α-phenylquinoline [2] respectively; lack of knowledge of the above was the reason for the incorrect interpretation of the mechanism of the quinaldine synthesis [3]. Pictet and Barbier attempted to synthesize γ-phenylquinoline from formanilide and acetophenone, but obtained α-phenylquinoline as a result [4]. Pictet and Bunzl effected the condensation of ethyl acetanilide expecting to obtain lepidine according to the scheme:



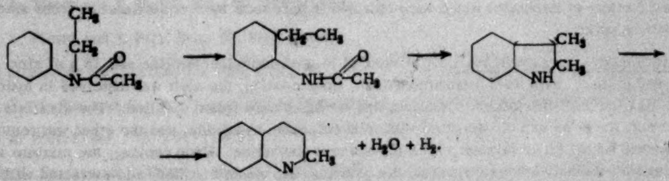
but obtained quinaldine; according to them, the mechanism of the reaction was as follows [5] (1):



(1)

o- Ethylacetanilide was found, by the authors, to be the intermediate product. However, acetylmethylaniline formed quinoline under these conditions [6]; the mechanism of the reaction in this case must be different. Pictet and Fert isolated o-acetyltoluidine from the reaction mixture [6]. They proposed that the reaction occurs by means of the intermediate formation of the methyl ketol (α-methylindole) because E. Fischer observed that the methyl ketol was transformed into quinoline upon heating in the presence of zinc chloride [7].

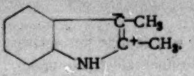
The synthesis of quinaldine from ethylacetanilide, by analogy, can be explained by the scheme (2):



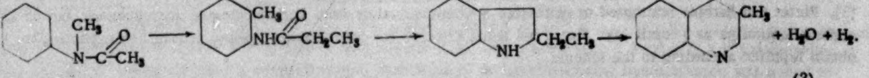
(2)

If the rupture of the indole ring occurs at the double bond between the α- and β-carbon atoms, which is more likely and is supported by the expansion of the pyrrole ring into the pyridine ring [8], then, in relation to which of the two methyl groups enters into the formation of the pyridine ring, either lepidine (case where the α-methyl group participates) or quinaldine can be formed. The formation of lepidine by means of this reaction can be of practical interest, as it is known that, when the ketol is passed through a weakly red hot tube, up to 17% of quinoline is formed [9].

In the present investigation it was shown that 2,3-dimethylindole formed quinaldine upon heating with zinc chloride, which confirms scheme (2). On the basis of the alternating polarity and the orientation effect, it can be suggested that the methyl group in the β-position will participate more readily in the formation of the pyridine ring than the methyl group in the α-position because the negative charge on the carbon atom of the α-methyl group is strengthened by the polarizing effect from the site of the NH-group, stabilizing its bond with the positive α-carbon atom of the ring, whereas the negative charge on the carbon atom of the β-methyl group is weakened by the effect of the NH-group which also affects the character of the charge on the β-carbon atom of the ring; thus the bond of the methyl group with the β-carbon atom must be more labile.

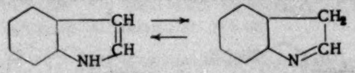


In the case of methylpropionylaniline or o-propionyltoluidine, β-methylquinoline is formed upon heating with zinc chloride; the reaction occurs by means of the intermediate formation of α-ethylindole according to scheme (3):



(3)

From the mechanism proposed by the authors for the Pictet reaction it can be concluded that it is impossible to obtain lepidine, as Pictet desired, by means of the reaction because the various homologs of indole formed are transformed into α- and β-substituted quinolines by the rupture of the ring. The only structure of indole which can explain the formation of lepidine is, apparently, the indolenyl:



The formation of quinoline derivatives by fusing homologs of indole with zinc chloride can be used for the identification of the various indole homologs which usually form picrates poorly or not at all whereas quinolines do so readily.

EXPERIMENTAL

The starting materials were the acylated derivatives of methylaniline, ethylaniline, and o-toluidine which had melting points corresponding to those given in the literature. o-Propionyltoluidine was obtained by the action of propionic acid on the amine [10]. Methylated acetyl and propionyl anilines were obtained by the action of metallic sodium and methyl iodide on the corresponding acyl derivatives [11]. The yields of the quinoline derivatives were small and, as a rule, did not exceed 0.5-0.7 g. The crude bases were identified by means of their picrates or styphnates which were obtained in pure form by recrystallization from alcohol to a constant melting point.

Synthesis of quinoline. Experiment 1. A mixture of 15 g of methylacetanilide and 15 g of zinc chloride was heated in an oil bath for 6 hours at 290-300°. Upon cooling, the melt was dissolved in hydrochloric acid, was made alkaline with 40% sodium hydroxide, and the bases were steam distilled. The distillate was extracted with ether, the ether extract was dried with solid potassium hydroxide, and the ether was removed. The crude bases were boiled for 15 minutes with 5 ml of acetic anhydride. Upon cooling, the mixture was made alkaline with saturated sodium carbonate solution, the quinoline was steam distilled, and extracted with ether. The picrate of the base had the m.p. 198° after three recrystallizations from alcohol. No depression was given upon a mixed melting point determination with quinoline picrate.

Experiment 2. A mixture of 15 g of acet-o-toluidine and 15 g of zinc chloride was heated in an oil bath for 6 hours at 290-300°. The separation and the purification of the bases was effected as in the first experiment. The picrate of the base isolated had the m.p. 200° after 3 recrystallizations. No depression was obtained on mixed melting point determination with quinoline picrate.

0.1 g substance: 14.2 ml N_2 (23°, 756 mm). Found %: N 15.83. $C_9H_7N \cdot C_6H_2(NO_2)_3OH$. Calculated %: N 15.64.

Experiment 3. 15 ml of phenylhydrazine and 15 ml of acetone were heated for one hour at 100°. The resulting acetone phenylhydrazone was heated with 25 g of zinc chloride for 3 hours at 290-300°. The isolated bases were processed in an analogous manner to the previous experiments. The picrate obtained from the isolated oil had the m.p. 200° after 4 recrystallizations from alcohol. No depression was obtained upon a mixed melting point determination with quinoline picrate.

Synthesis of quinaldine. Experiment 4. A mixture of 15 g of ethylacetanilide and 15 g of zinc chloride was heated for 4 hours in an oil bath to 260-270°. The isolation of the picrate of the base was effected as reported above. No depression was obtained upon a mixed melting point determination with quinaldine picrate. The styphnate of the base had the m.p. 211°.

Experiment 5. 15 ml of phenylhydrazine, 20 ml of methyl ethyl ketone, and 25 g of zinc chloride were used. The experiment was conducted analogously to the third experiment. The picrate of the base isolated had the m.p. 190°. No depression was obtained upon a mixed melting point determination with quinaldine picrate. The styphnate of the base had the m.p. 212°.

0.1145 g substance: 15.6 ml N_2 (22°, 754 mm). Found %: N 15.23. $C_{10}H_9N \cdot C_6H_2(NO_2)_3OH$. Calculated %: N 15.05.

Synthesis of 3-methylquinoline. A picrate of a base with m.p. 186°, giving a depression upon a mixed melting point determination with quinaldine picrate was isolated upon the reaction of methylpropionylaniline with zinc chloride in a manner analogous to the above experiment. The styphnate of the base had the m.p. 185° which corresponds to β-methylquinoline.

SUMMARY

1. It was shown that the α- and β-substituted quinolines were formed upon heating alkylated acetanilides and acylated o-toluidines with zinc chloride.

2. A general mechanism was proposed for the formation of quinoline derivatives from alkylated acyl anilides by the Pictet reaction.

3. On the basis of the proposed mechanism for the Pictet reaction it can be concluded that γ-alkyl quinolines cannot be obtained by means of this reaction.

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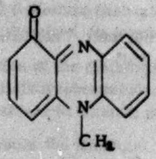
* See Consultants Bureau English translation, p. 493.

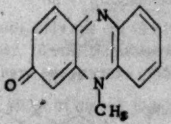
N-ALKYLPHENAZINONES. I

S. B. Serebryanyi

N-Alkylphenazinones have been little studied in spite of the fact that this group includes the antibiotic of *B. pyocyaneus* – pyocyanine. The preparation of a small amount of N-alkylphenazinones has been reported in the literature [1-5]. The simplest N-alkylphenazinones were obtained by the oxidation of aqueous solutions of quaternary phenazine salts. It was shown [2] that, in relation to the method of oxidation of phenazine methylmethosulfates, isomeric N-alkylphenazinones were obtained: photochemical oxidation leads to the formation of blue 10-methylphenazinone-1 (pyocyanine), while oxidation of the same salt with potassium permanganate in alkaline media results in the formation of the red 10-methylphenazinone-3.



10-Methylphenazinone-1
(blue)

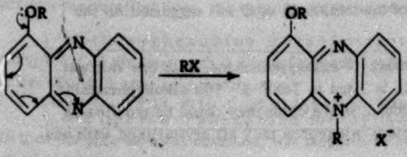


10-Methylphenazinone-3
(red)

The same picture is obtained upon the oxidation of phenazine ethylethosulfate.

The author, having a series of alkoxy derivatives of phenazine [6-9] at his disposal, prepared a series of new alkoxy derivatives of 10-ethylphenazine by the oxidation of aqueous solutions of their quaternary salts with potassium permanganate in alkaline media.

Several (more than two) isomeric N-alkylphenazinones can be formed upon the oxidation of quaternary salts of substituted phenazines; for example, 1-alkoxyphenazines. The structure of these N-alkylphenazinones must depend on the structure of the quaternary salts. To answer the question of the possible structures of the quaternary phenazine salts, the electronic character and the direction of the influence of the substituent must be considered. Alkoxy- and hydroxy groups belong to the series of electropositive substituents. When found in position 1 or 3 of the benzene ring of phenazine, these groups, as a result of the displacement of the electrons, cause an increase in the electron density of one of the nitrogen atoms of this heterocycle, and, apparently upon the formation of salts, the proton or alkyl will add only to this nitrogen atom.



Experimentally it was shown that the structure of the quaternary 1-hydroxy- and 1-methoxyphenazine salts agreed only with these rules. For example, in 1938, Hillemann [10] showed that, upon the action of dimethyl sulfate on 1-methoxyphenazine, the methyl group added to the nitrogen atom in position 10.

It was shown that, upon the desalkylation of 1-methoxyphenazine ethylethosulfate with 60% sulfuric acid, blue 10-ethylphenazinone-1 was formed. Therefore, the alkyl group in the quaternary salt of 1-alkoxyphenazine is also found on the nitrogen in position 10. In the case of two hydroxy or alkoxy groups, the direction of their effect may be concurrent or opposed. In the latter case, two isomeric salts must be expected.

TABLE 1

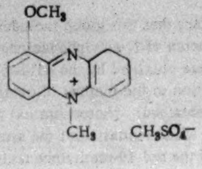
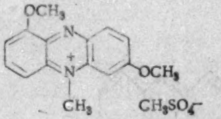
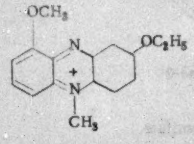
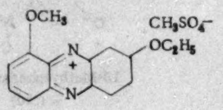
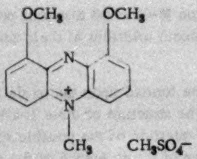
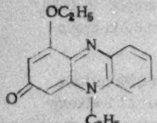
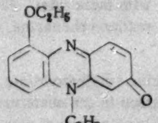
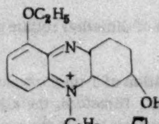
Expt. No.	Structure of salts	Melting point	Appearance
I		201°*	Dark, red needles
II		Does not melt up to 300°	Red needles
III	 or 	197°*	Red needles
IV		Does not melt up to 300°	Violet needles

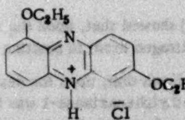
Table 1 lists the structures, melting points, and the external appearance of the alkoxyphenazine methylmethosulfates obtained by the action of dimethyl sulfate on the corresponding bases. The structure of the quaternary salts (I) was shown experimentally, the structure of the remaining salts was suggested on the basis of the above given rule.

It must be pointed out that, upon the alkylation of 1-methoxy- 7- ethoxyphenazine, only one salt was isolated instead of the two possible: the structure of the salt, (III), is listed in Table 1. The alkoxyphenazine methylmethosulfates obtained are readily soluble in water and alcohol in the cold; they could be purified by several recrystallizations from a mixture of alcohol and amylacetate, whereupon they all crystallized with one molecule of water.


A


B


C


D

Aqueous solutions of salts (I), (II), and (IV) are completely stable on prolonged storage, while the aqueous solution of salt (III) hydrolyzes on standing with the separation of the free base.

Upon oxidation of 1-ethoxyphenazine ethylethosulfate, the formation of three isomeric 10-ethylphenazinones could be expected: 2 red (1-ethoxy-10-phenazinone-3 and 1-ethoxy-10-ethylphenazinone-6) and one blue (1-ethoxy-10-ethylphenazinone-8). It was found that alkoxy- and dialkoxyphenazinone ethylethosulfates cannot be oxidized photochemically. In contrast, the oxidation of these salts with potassium permanganate in alkaline media proceeds readily and smoothly, and leads to the formation of red 10-ethylphenazinones which, apparently, are derivatives of 10-ethylphenazinone-3 or 10-ethylphenazinone-6.

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* Melts with decomposition. The temperature here and subsequently is given without correction.

In one case, when 1-ethoxyphenazine ethylethosulfate was oxidized, two red isomers of 1-ethoxy-10-ethylphenazinone were obtained: with m.p. 211-212° and 195-197°, the structures of which can be represented by the formulas A and B.

The preparation with m.p. 211-212° dissolves in dilute hydrochloric acid with a red color, while the preparation with m.p. 195-197° – with a yellow color. The color of the hydrochloric acid solution of the latter substance is the same as that of 1,6-diethoxyphenazine, D. Apparently when 1-ethoxy-10-ethylphenazinone is dissolved in hydrochloric acid, hydroxyethoxyethylphenazine chloride, C, is formed.

The closeness of the colors of the hydrochloric acid solutions of 1-ethoxy-10-ethylphenazinone with m.p. 195-197° and 1,6-diethoxyphenazine, leads to the conclusion that the phenazinone is 1-ethoxy-10-ethylphenazinone-6, and therefore, its isomer with m.p. 211-212° is 1-ethoxy-10-ethylphenazinone-3.

Upon oxidation of the dialkoxyphenazine ethylethosulfates, only one red 10-ethylphenazinone was obtained. 10-Ethyldialkoxyphenazinones are derivatives of either, 10-ethylphenazinone-3, [illegible] or 10-ethylphenazinone-6; whereas preparation (X) can only have one structure (Table 2).

Table 2 contains the structures, melting points, and the yields of the red 10-ethylphenazinones obtained.

The red N-alkylphenazinones are readily soluble in alcohol, and chloroform, and insoluble in ether, petroleum ether, and ligroin. They are noticeably soluble in cold water and readily soluble in hot water. Upon dissolving 10-ethylphenazinones in aqueous alkali solutions, the color remains unchanged from that in the aqueous solution. Dilute mineral acids dissolve 10-ethylphenazinones in the cold, whereupon the color of the acidic solution differs from the color of the aqueous solution, which is related to the formation of the hydrochloride salt of the alkoxy derivatives of 2-hydroxyphenazine (see above).

EXPERIMENTAL

Alkoxyphenazine methylmethosulfates.

Alkoxyphenazine methylmethosulfates were prepared by heating alkoxyphenazines with an excess of freshly distilled dimethyl sulfate in nitrobenzene in a sealed tube for 5-15 min. on a boiling water bath. The reaction product was treated with dry ether and filtered. In order to separate the unreacted bases, the nitrobenzene, and the excess dimethyl sulfate, the salt obtained was treated with boiling petroleum ether. The methylmethosulfates were purified by five recrystallizations from a mixture of alcohol and amyl acetate. After four recrystallizations, the melting point did not change.

1-Methoxyphenazine methylmethosulfate (I). 0.7 g of the crude salt was obtained by heating 0.5 g of the base with 0.8 ml of dimethyl sulfate in 5 ml of nitrobenzene for 5 min. 0.2 g of the pure salt was obtained after recrystallization.

Found %: N 8.14, 8.16. $C_{15}H_{16}O_5N_2S \cdot H_2O$. Calculated %: N 7.92.

1,6-Dimethoxyphenazine methylmethosulfate (II). 0.39 g of the impure salt from which, 0.15 g of the pure salt was obtained, was prepared by heating 0.4 g of the base and 0.4 g of dimethyl sulfate in 2 ml of nitrobenzene for 5 min.

Found %: N 7.34. $C_{16}H_{18}O_6N_2S \cdot H_2O$. Calculated %: N 7.30.

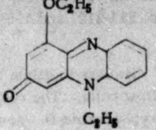
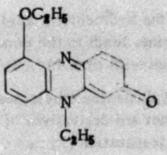
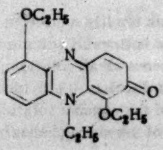
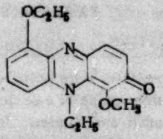
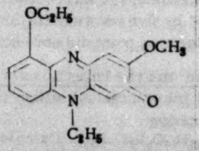
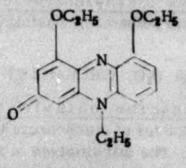
1-Methoxy-7-ethoxyphenazine methylmethosulfate (III). A mixture of 0.5 g of the base, 0.8 ml of dimethyl sulfate, and 2.5 ml of nitrobenzene was heated for 15 min. 0.8 g of the impure salt was obtained; after purification, 0.1 g. The salt dissolved in water with an orange yellow color. The aqueous salt solution, upon standing for 24 hours, hydrolyzed with the separation of the free base.

Found %: N 7.02, 6.98. $C_{17}H_{20}O_6N_2S \cdot H_2O$. Calculated %: N 7.05.

1,8-Dimethoxyphenazine methylmethosulfate (IV). The quaternary salt, in amount of 0.67 g., was obtained by heating 0.5 g of the base, and 0.8 ml of dimethyl sulfate in 2.5 ml of nitrobenzene for 10 min. 0.2 g of the pure salt was obtained. Long, dark, violet needles. The aqueous solution was colored dark red.

Found %: N 7.04, 7.02. $C_{16}H_{18}O_6N_2S \cdot H_2O$. Calculated %: N 7.30.

TABLE 2

Expt. No.	Name of preparation	Formula	Melting point	Yield from the base, in %
V	1-Ethoxy-10-ethylphenazinone-3		211-212*	90
VI	1-Ethoxy-10-ethylphenazinone-6		195-197	
VII	1,5-Diethoxy-10-ethylphenazinone-6		205	69
VIII	1-Ethoxy-5-methoxy-10-ethylphenazinone-6		225-226	44
IX	1-Ethoxy-7-methoxy-10-ethylphenazinone-6		185-186	46
X	1,8-Diethoxy-10-ethylphenazinone-3		211-212*	52

10-Ethylphenazinones

10-Ethylphenazinone-1. This phenazinone was prepared by the desalkylation of 1-methoxyphenazine ethylethosulfate. The quaternary salt was obtained from 0.35 g of the base in the same manner as 1-ethoxyphenazine ethylethosulfate (see below). 0.4 g of a pure preparation was obtained by treating the impure quaternary salt with ether. The salt obtained was dissolved in 10 ml of 60% sulfuric acid, the solution heated on an oil bath to

175°, and kept at this temperature for 3 min., and then poured into water. The dilute sulfuric acid solution was filtered and made alkaline with a 5% sodium hydroxide solution. The color of the solution changed from red to blue. The alkaline solution was extracted with chloroform, and the chloroform solution was extracted with small amounts of 5% hydrochloric acid. The acidic solution was made alkaline and once more extracted with chloroform. 0.1 g of crystalline 10-ethylphenazinone-1 was obtained after the removal of the solvent. Blue needles with m.p. 170-173° were obtained on recrystallization from water.

Derivatives of 10-ethylphenazinone-3 and 10-ethylphenazinone-6 (red phenazinones). These compounds were obtained by the oxidation of ethoxy substituted phenazine ethylethosulfates. The ethylethosulfates were obtained by heating the bases with excess neutral diethyl sulfate and nitrobenzene. The heating was conducted on an oil bath at 130-140° for 1-2 hours. The salts obtained were treated with small quantities of water, the aqueous solution was extracted with benzene to remove the nitrobenzene and excess diethyl sulfate, and the unreacted base, and then the aqueous solution was filtered. Potassium permanganate was dissolved in the aqueous solution of the quaternary salt, and a small excess of 10% sodium hydroxide solution was added dropwise with mechanical stirring in 45 min. The phenazinone, which formed on standing over night, was extracted with chloroform, the solvent removed, and the preparation purified by crystallization from water or from a mixture of ligroin and dioxane.

On treating the benzene solution with 15% hydrochloric acid followed by precipitation with ammonia, phenazine bases which did not react during the preparation of the ethylethosulfates were regenerated.

1-Ethoxy-10-ethylphenanzinone-3 and 1-ethoxy-10-ethylphenazinone-6 (V and VI). The ethylethosulfate was obtained by heating 1 g of 1-ethoxyphenazine and 3 ml of diethyl sulfate in 5 ml of nitrobenzene for 50 min. In order to oxidize it, 3.4 g of potassium permanganate and 9 ml of 10% sodium hydroxide were added to the solution of the salt in 60 ml of water. 0.75 g of a red substance with m.p. 191-205°, was obtained. The substance was shown to be a mixture of two isomeric red phenazinones. 0.3 g of an isomer with m.p. of 208-211° was isolated from the mixture after recrystallization from water. It was recrystallized from water for analysis. Dark, red needles, m.p. 211-212°.

Found %: N 10.49. $C_{16}H_{16}O_2N_2$. Calculated %: N 10.44.

The substance dissolved in dilute hydrochloric acid with a red color. The aqueous mother liquor from the isolation of the isomer with m.p. 208-211° was extracted with chloroform. After removal of the chloroform, the solid residue was recrystallized from a mixture of ligroin and dioxane. 0.3 g of red needles of 1-ethoxy-10-ethylphenazinone-6 with m.p. 195-197° was isolated. For analysis the preparation was recrystallized from the above mixture; the melting point did not change.

Found %: N 10.25, 10.60. $C_{16}H_{16}O_2N_2$. Calculated %: N 10.44.

A mixed melting point determination with the isomeric phenazinone (V) gave a 15-20° depression. 1-Ethoxy-10-ethylphenazinone-6 is readily soluble in cold water. Its hydrochloric acid solution is colored yellow.

1,5-Diethoxy-10-ethylphenazinone-6 (VII). The ethylethosulfate was obtained by heating 1 g of the base with 3 ml of diethyl sulfate and 3 ml of nitrobenzene for 2 hours. The processing of the salt and its oxidation was effected as previously. The yield of the impure preparation was 0.6 g. For analysis, the preparation was recrystallized three times from hot water. Long, thread-like, violet needles, m.p. 205°.

Found %: N 8.96, 8.78. $C_{18}H_{20}O_3N_2$. Calculated %: N 8.94.

1-Ethoxy-5-methoxy-10-ethylphenazinone-6 (VIII). The ethylethosulfate was obtained from 0.2 g of the base with the same method as in the previous case; the same oxidation method was used. The yield of the substance with m.p. 223-225° was 0.1 g. For analysis, the substance was recrystallized two times from hot water. Violet needles, m.p. 225-226°.

Found %: N 9.42. $C_{17}H_{18}O_3N_2$. Calculated %: N 9.39.

1-Ethoxy-7-methoxy-10-ethylphenazinone-6. A solution of 1 g of the base and 2 ml of diethyl sulfate in 3 ml of nitrobenzene was heated for 1hour and 15 min. 4 g of potassium permanganate and 10 ml of 10% sodium hydroxide solution were added to a solution of the salt in 50 ml of water. 0.39 g of a substance with m.p. 183-185° was obtained. For analysis, it was recrystallized from water. Dark red needles, m.p. 185-186°.

Found %: N 9.29, 9.43. $C_{17}H_{18}O_3N_2$. Calculated %: N 9.39.

1,8-Diethoxy-10-ethylphenazinone-3 (X). The quaternary salt was prepared by heating 0.5 g of 1,8-diethoxyphenazine and 0.7 ml of diethyl sulfate in 1 ml of nitrobenzene for 1 hour. A solution of the salt in 45 ml of water was oxidized with 1.3 g of potassium permanganate with the addition of 5 ml of a 10% sodium hydroxide solution 0.24 g of dark red crystals with m.p. 206-208° was obtained. For analysis, the preparation was recrystallized from a mixture of dioxane and ligroin.

Dark red needles, m.p. 211-212°.

Found %: N 8.83. $C_{18}H_{20}O_3N_2$. Calculated %: N 8.94.

The author wishes to express his gratitude to Academician of the Academy of Sciences of the Ukranian S.S.R., prof. A.I. Kiprianov, for valuable suggestions during this investigation

SUMMARY

1. The following methylmethosulfates were obtained: 1-methoxy-, 1,6-dimethoxy-, 1,8-dimethoxyphenazines, and 1-ethoxy-7-methoxyphenazine.

2. 10-Ethylphenazinone-1 was formed upon the desalkylation of 1-methoxyphenazine ethylethosulfate; this operation determined the structure of the above salt.

3. It was shown that quaternary alkoxyphenazine salts were not oxidized photochemically.

4. Five new derivatives of 10-ethylphenazinone-3 and one of 10-ethylphenazinone-6 were obtained by the oxidation of aqueous solutions of alkoxyphenazine ethylethosulfates with potassium permanganate in alkaline media.

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CYANINE DYES CONTAINING FLUORINE

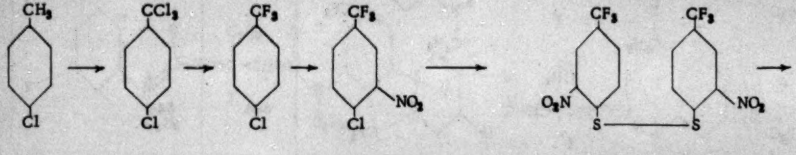
II. CYANINE DYES FROM DERIVATIVES OF 6-FLUORO- AND 5-TRIFLUOROMETHYLBENZOTHIAZOLES

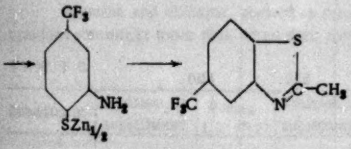
A. I. Kiprianov and L. M. Yagupolsky

In the previous communication [1] the preparation of a series of cyanine dyes from derivatives of 6-fluorobenzothiazole were reported. In the present communication, the synthesis of dyes containing a fluorine atom and a CF$_3$- group in the 5,5'- positions of the benzothiazole ring are given.

In the literature mostly in patents, are reported anthraquinone, indigoid, and azo dyes with a trifluoromethyl group as a substituent. Several of these have been prepared on an industrial scale. Up to now, the least studied were the trifluoromethyl derivatives of the cyanine dyes. Only one patent reporting asymmetrical trimethinecyanines, containing a CF$_3$- group in the benzimidazole ring has been published [2]. The absorption maxima of these dyes are not given in the patent, and for this reason, no conclusion on the effect of the CF$_3$- group on the color can be made.

In order to prepare thiacyanine dyes containing a CF$_3$-group, 2-methyl-5-trifluoromethylbenzthiazole, unreported in the literature, was synthesized for use as the starting material according to the following scheme:





p-chlorobenzotrifluoride [3] and 3-nitro-4-chlorobenzotrifluoride [4] are reported in the literature. 3-Nitro-4-chlorobenzotrifluoride was transformed into the disulfide by means of an aqueous -alcoholic solution of Na$_2$S$_2$. The disulfide was reduced with zinc dust and a mixture of glacial acetic and hydrochloric acids [5]. The zinc salt of 5-trifluoromethyl-1,2-aminothiophenol, obtained in this manner, was transformed into 2-methyl-5-trifluoromethylbenzthiazole by boiling with acetic anhydride.

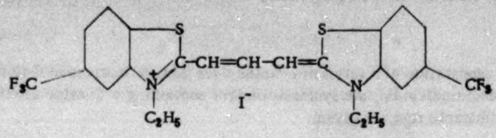
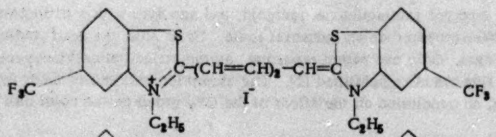
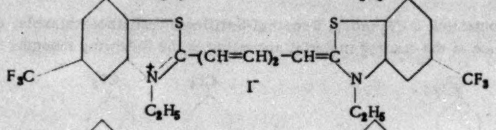
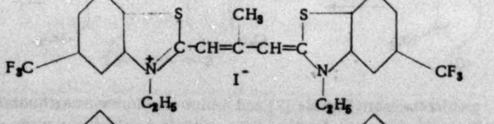
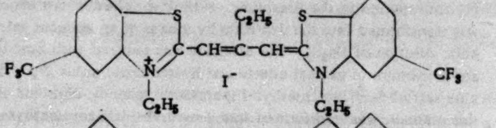
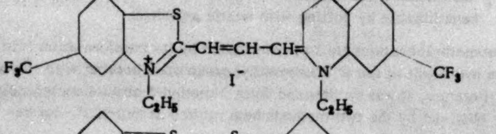
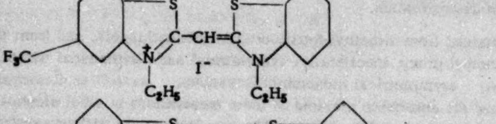
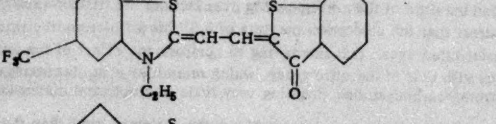
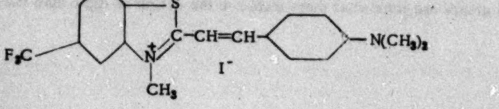
The structure of the 2-methyl-5-trifluoromethylbenzthiazole was determined by its transformation into 2-methylbenzthiazole-5-carboxylic acid by the hydrolysis of the trifluoromethyl group upon heating with sulfuric acid. Since this acid was not reported in the literature, it was synthesized from 2-methyl-5-aminobenzthiazole via 2-methyl-5-cyanobenzthiazole. The acids obtained by the two methods both melted at 202-203°. No depression was given upon a mixed melting point determination.

The methiodide and ethiodide were obtained from 2-methyl-5-trifluoromethylbenzthiazole, and from these were obtained 9 thiacyanines with a trifluoromethyl group, specifically: symmetrical and asymetrical trimethinecyanines, penta- and heptamethinecyanines, asymmetrical monomethinecyanines, as well as merocyanine and the dye- styryl. The structural formulas and the absorption maxima of these preparations in ethyl alcohol are listed in Table 1; for comparison, the absorption maxima of the corresponding dyes lacking the trifluoromethyl group are also given. From Table 1, it is apparent that the absorption maxima of 5,5'- bis-trifluoromethylthiacarbocyanine) does not differ from those of the unsubstituted dyes. It is interesting to compare the effect of the trifluoromethyl group on the color of thiacarbocyanines with that of the nitro group, which resembles it in electronegative properties. E.D.Sych [6] synthesized 5,5'-dinitrothiacarbocyanines, differing very little in absorption maximum (560 mμ) from the unsubstituted dyes.

The thiacyanines with trifluoromethyl groups are somewhat more stable to the action of light than the corresponding unsubstituted dyes.

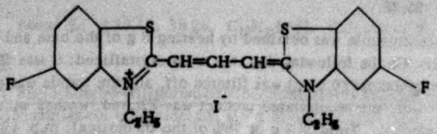
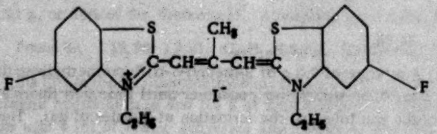
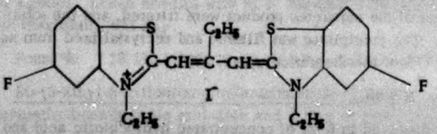
For the synthesis of 5,5'dinitrothiocarbocyanines, it was necessary to obtain 2-methyl-5-fluorobenzothiazole

TABLE 1

Expt. No.	Formula	λ_{max} (in mμ)	λ_{max} of dye without CF_3-group
I		557	558
II		651	651
III		–	755
IV		544	544
V		550	550
VI		570	580
VII		425	422
VIII		545	556
IX		540	530

reported in the literature — as the starting material. It was obtained from 2-methyl-5-aminobenzthiazole by diazotizing with sodium nitrite in a solution of fluoboric acid. The precipitated fluoborate diazonium compound was decomposed by heating in decalin. The ethiodide of this base was obtained, and from it, three thiacarbocyanines with fluorine atoms in the 5,5'-positions were obtained (Table 2).

TABLE 2

Expt. No.	Formula	λ_{max} in mμ	λ_{max} of dye without fluorine
X	 S S C—CH=CH—CH=C N N F F I⁻ C₂H₅ C₂H₅	562	558
XI	 S CH₃ S C—CH=C—CH=C N N F F I⁻ C₂H₅ C₂H₅	546	545
XII	 S C₂H₅ S C—CH=C—CH=C N N F F I⁻ C₂H₅ C₂H₅	550	550

Fluorine and chlorine, present as substituents in 5,5'-positions, displace the absorption maxima of thiacarbocyanines somewhat more than when they are present in position 6,6'. This is apparent from Table 3.

TABLE 3

Substituent	Position of substituent	λ_{max} (in mμ)	Position of substituent	λ_{max} (in mμ)
—	—	558	—	558
Fluoro	5	562	6	558 [1]
Chloro	5	562.5 [7]	6	560 [8]

EXPERIMENTAL

Intermediate product

4,4'-Bis(trifluoromethyl)-2,2'-dinitrodiphenyldisulfide. 4 g of $Na_2S \cdot 9H_2O$ was dissolved in 35 ml of alcohol in a 100 ml round bottomed flask connected with a reflux condenser. 0.53 g of finely pulverized sulfur was added to the solution and the liquid heated for 1 hour until the sulfur dissolved. The hot solution was added in small portions to a boiling solution of 7.2 g of 3-nitro-4-chlorobenzotrifluoride in 10 ml of alcohol. When all of the disulfide was added, the mixture was heated on the water bath for 3 hours. After cooling, the mixture of disulfide and sodium chloride was heated and washed with water. After recrystallization from alcohol, the product was obtained in the form of long yellow needles with m.p. 161-162°. Yield 5 g or 70% of the theoretical.

Found %: N 6.45, 6.52. $C_{14}H_6O_4N_2S_2F_6$. Calculated %: N 6.30.

2-Methyl-5-trifluoromethylbenzthiazole. 10.5 g of 4,4'-bistrifluoromethyl-2,2'-dinitrodiphenyldisulfide was dissolved by heating in 65 ml of glacial acetic acid. 18 g of zinc dust and 45 ml of concentrated hydrochloric acid was added to the solution in small portions. The reduction took 1 hour. At the end of the reaction, the yellow solution became colorless. The solution was filtered, diluted, with 3-fold quantity of water, sodium acetate added until the absence of an acid reaction on Congo, and allowed to stand for 1 hour. A colorless precipitate of the zinc mercaptide formed. The product was dried in a drying cabinet at 40°. The yield of the dry product was 10 g, or 94% of the theoretical. 10 g of the zinc salt of 5-trifluoromethyl-1,2-aminothiophenol was heated to boiling with 25 ml of acetic anhydride for 3 hours. The solution was placed into a flask for steam distillation, made weakly alkaline with ammonia, and the product steam distilled. The product crystallized from the distillate, was filtered and dried. After recrystallization from petroleum ether – white sheets with m.p. 63-64°.

Yield 62% of the theoretical.

Found %: N 6.63, 6.67. $C_9H_6NSF_3$. Calculated %: N 6.45.

The methiodide of 2-methyl-5-trifluoromethylbenzthiazole was obtained by heating 0.5 g of the base and 0.3 g of dimethyl sulfate on the boiling water bath for 3 hours. The product was washed with benzene and precipitated from an aqueous solution with potassium iodide. After recrystallization from aqueous alcohol, the yield was 0.72 g or 88% of the theoretical; m.p. 303-304°.

Found %: 35.60. $C_{10}H_9NSF_3$. Calculated %: 35.38.

The ethiodide of 2-methyl-5-trifluoromethylbenzthiazole was obtained by heating 3 g of the base and 2.25 g of diethyl sulfate on the boiling water bath for 7 hours. On the following day, the mass crystallized; it was dissolved in water. The unreacted 2-methyl-5-trifluoromethylbenzthiazole (0.25 g) was filtered off, and the iodide was precipitated from the solution with a solution of potassium iodide, the precipitated product was filtered, washed with water, benzene, and ether, and recrystallized from aqueous alcohol. Yield, 3.3 g or 70% of the theoretical; m.p. 197° with decomposition.

Found %: 33.82. $C_{11}H_{11}NSF_3$. Calculated %: 34.05.

2-Methyl-5-benzothiazolecarboxylic acid. a) A mixture of 0.3 g of 2-methyl-5-trifluoromethylbenzthiazole and 2 g of sulfuric acid (monohydrate) was heated in a test tube with an air condenser until hydrogen fluoride began to separate, which could be detected by the etching of the test tube and the formation of bubbles of gas. The heating was continued intermittently for 3 hours. After the separation of the bubbles of HF ceased, the reaction mixture was cooled, poured on ice, and made alkaline. Traces of the unreacted product were filtered, and the solution was acidified with acetic acid to a weakly acid reaction. The precipitate was filtered and recrystallized from aqueous methanol. Yield of colorless, long needles, 0.2 g or 77% of the theoretical; m.p. 202°.

Found %: N 7.42. $C_9H_7O_2NS$. Calculated %: N 7.25.

b) 3 g of 2-methyl-5-aminobenzthiazole was dissolved in 6 ml of concentrated hydrochloric acid and 4.5 ml of water, and was diazotized with cooling with 1.28 g sodium nitrite in 6 ml of water. The diazo compound was added in small portions to a solution of 5 g of $CuSO_4$ and 4.5 g of NaCN in 30 ml of water; the mixture was then heated for 1 hour on the boiling water bath. The solution was made alkaline, the precipitate was filtered, and washed with water, and the product extracted from it with boiling toluene. (3 times with 15 ml). The toluene solution was concentrated. The precipitated product was dissolved in aqueous alcohol. The yield of colorless 2-methyl-5-cyanobenzthiazole was 1.11 g or 35% of the theoretical; m.p. 156-157°.

Found %: N 16.11. $C_9H_6N_2S$. Calculated %: N 16.09.

0.2 g of 2-methyl-5-cyanobenzthiazole was boiled for 1.5 hours with 4.5 ml of concentrated sulfuric acid and 3 ml of water. After cooling, the mixture was diluted with water, made alkaline, filtered, and acidified with acetic acid to litmus. The precipitated acid was filtered and recrystallized from aqueous alcohol. Colorless needles with m.p. 203°. Yield 0.19 g or 86% of the theoretical. No depression was obtained upon a mixed melting point determination with the acid obtained by the hydrolysis of 2-methyl-5-trifluoromethylbenzthiazole.

Found %: N 7.36. $C_9H_7O_2NS$. Calculated %: N 7.25.

2-Methyl-5-fluorobenzthiazole. 5 g of 2-methyl-5-aminobenzthiazole was dissolved in 46 g of 40% fluoboric acid in a platinum dish, cooled well, and diazotized by the dropwise addition of a solution of 2.2 g of sodium nitrite in 5 ml of water. After standing for 45 minutes in a freezing mixture, the precipitated diazonium fluoborate was filtered, washed with alcohol, and ether, and dried for 24 hours in a vacuum desiccator. Decomposition temperature, 147°. Yield, 6.73 g or 84% of the theoretical.

6.5 g of the diazonium fluoborate was placed in a 250 ml round bottomed flask, and 50 ml of decalin was added to it. The flask was connected to a well cooled reflux condenser, and heated until the evolution of BF_3 ceased; the mixture was then heated for 10 minutes more. After cooling, the product was extracted from the decalin with 10% hydrochloric acid (3 times with 40 ml), and the aqueous layer separated. The last traces of decalin were steam distilled from the acidic solution; the solution was then neutralized with sodium carbonate, and the distillation resumed whereupon 5-fluoro-2-methylbenzthiazole distilled in the form of an oily liquid with the odor of a thiazole. The product was extracted with ether (3 times with 50 ml), the ether solution was dried with $MgSO_4$, the ether then removed, and the preparation vacuum distilled. Colorless, oily liquid with b.p. 110-112° at 7 mm. Yield 1.5 g or

30% of the theoretical based on the amine used; n_D^{20} 1.5864.

Found %: N 8.53, 8.59. C_8H_6NSF. Calculated %: N 8.38.

The ethiodide of 2-methyl-5-fluorobenzthiazole was obtained by heating 1.25 g of the base and 1.25 g of diethyl sulfate on the boiling water bath. After 5 hours, the mixture crystallized. The yield of the benzene and ether-washed raw product was practically quantitative. The iodide was precipitated from an aqueous solution with potassium iodide. After recrystallization from aqueous alcohol, the yield was 1.9g or 75% of the theoretical; m.p. 195° with decomposition.

Found %: I 39.12, 39.26. $C_{10}H_{11}NSFI$. Calculated %: I 39.32.

DYES

Bis-[3-Ethyl-5-trifluoromethylbenzthiazole-(2)]trimethinecyanine iodide (I). 0.5 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide and 0.5 g of orthoformic ester were boiled for 30 minutes with 3.5 ml of acetic anhydride. The yield of the crude product was 0.26 g, after recrystallization from 60 ml of ethyl alcohol, the yield was 0.21 g, or 50% of the theoretical. Absorption maximum, 557 mμ; m.p. 269-270° with decomposition.

Found %: I 19.99, 19.91. $C_{23}H_{19}N_2S_2F_6I$. Calculated %: I 20.22.

Bis-[3-Ethyl-5-trifluoromethylbenzthiazole-(2)]-pentamethinecyanine iodide (II). 0.17 g of β-anilinoacroleinanil hydrochloride and 0.5 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide were boiled for 20 minutes with 4 ml of acetic anhydride and 3 drops of pyridine. The precipitated dye was recrystallized from methyl alcohol. Green needles with m.p. 262-263° with decomp. Yield 0.21 g or 50% of the theoretical. Absorption maximum, 651 mμ.

Found %: I 19.11, 19.13. $C_{25}H_{21}N_2S_2F_6I$. Calculated %: I 19.41.

Bis-[3-Ethyl-5-trifluoromethylbenzthiazole-(2)]heptamethinecyanine iodide (III). 0.5 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide and 0.19 g of glutaconaldehydeanilanilide hydrochloride were dissolved by boiling in 5 ml of absolute alcohol; then a solution of 0.03 g of Na in 1.5 ml of absolute alcohol was added, and the mixture was boiled for 1 minute. The precipitated crystals were recrystallized from methyl alcohol. Yield 0.1 g or 22.2% of the theoretical. Bright green crystals with m.p. 158-159° with decomp. The absorption maximum of this dye is beyond the limits of the visual spectrum.

Found %: I 18.35. $C_{27}H_{23}N_2S_2F_6I$. Calculated %: I 18.67.

Bis-[3-Ethyl-5-trifluoromethylbenzthiazole-(2)]-9-methyltrimethinecyanine iodide (IV). 0.37 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide and 0.4 g of orthoacetic ester was heated for 40 minutes with 3 ml of acetic anhydride and 3 drops of pyridine. The precipitated dye was recrystallized from alcohol. Long violet needles with m.p. 288-289° with decomp. Yield 0.12 g or 37.5% of the theoretical. Absorption maximum, 544 mμ.

Found %: I 19.49. $C_{24}H_{21}N_2S_2F_6I$. Calculated %: I 19.77.

Bis-[3-Ethyl-5-trifluoromethylbenzthiazole-(2)]-9-ethyltrimethinecyanine iodide (V). 0.25 g of 2-methyl-5-trifluoromethylbenzthiazole and 0.2 g of diethyl sulfate were heated for 7 hours on the boiling water bath. The solidified salt was washed with benzene and ether, and dried; it was heated with 0.4 g of orthopropionic ester for 40 minutes in 3 ml of pyridine. The dye was precipitated with an aqueous solution of potassium iodide, and recrystallized from ethyl alcohol. Yield 0.08 g or 26%. Red violet needles with m.p. 216-218° with decomp. Absorption maximum, 550 mμ.

Found %: I 19.09. $C_{25}H_{23}N_2S_2F_6I$. Calculated %: I 19.37.

[3-Ethyl-5-trifluormethylbenzthiazole-(2)][1-ethylquinoline-(2)]trimethinecyanine iodide (VI). 0.42 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide, 0.5 g of 2-acetanilidovinylquinoline ethiodide, and 0.4 g of sodium acetate were heated for 30 minutes on the boiling water bath with 3 ml of acetic anhydride. The dye was precipitated with ether, filtered, washed with water, and recrystallized from 60 ml of alcohol. Yield 0.22 g or 35.4% of the theoretical; m.p. 276-277° with decomp. Absorption maximum, 570 mμ.

Found %: I 22.69. $C_{24}H_{22}N_2SF_3I$. Calculated %: I 22.96.

[3-Ethyl-5-trifluoromethylbenzthiazole-(2)][3-ethylbenzthiazole-(2)] methinecyanine iodide (VII). 0.2 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide, 0.18 g of 2-methylmercaptobenzthiazole ethiodide, and 0.1 g of anhydrous sodium acetate was boiled with 3 ml of absolute alcohol for 1 hour. After 2 recrystallizations from alcohol, lemon yellow needles with m.p. 269-270° with decomp. were obtained. Yield 0.18 g or 65% of the theoretical. Absorption maximum, 425 mμ.

Found %: I 23.66. $C_{20}H_{18}N_2S_2F_3I$. Calculated %: I 23.78.

2-(3-Ethyl-5-trifluoromethylbenzthiazolenilidene-2'-ethylidene)-3-oxo-2,3-dihydrothionaphthene (VIII). 0.25 g of 2-methyl-5-trifluoromethylbenzthiazole ethiodide, 0.17 g of 3-hydroxythionaphthen-2-aldehyde anil, and 0.22 g of anhydrous sodium acetate were heated for 45 minutes with 3 ml of absolute alcohol. The precipitate was washed with water, and recrystallized from alcohol. Red violet needles with m.p. 294-296°. Yield 0.19 g or 70% of the theoretical. The preparation showed solvatochromism. Its absorption maximum in alcohol solution was 545 mμ, and in benzene, 520 mμ.

Found %: N 3.55. $C_{20}H_{14}ONS_2F_3$. Calculated %: N 3.45.

2-p-Dimethylaminostyryl-5-trifluormethylbenzthiazole ethiodide (IX). 0.3 g of trifluormethylbenzthiazole methiodide and 0.14 g of p-dimethylaminobenzaldehyde were boiled for 30 minutes with 3 ml of acetic anhydride. The precipitated dye was recrystallized from alcohol. Red-violet needles with m.p. 237-238°. Yield 0.22 g or 55% of the theoretical. Absorption maximum, 540 mμ.

Found %: I 24.89. $C_{20}H_{20}N_2SF_3I$. Calculated %: I 25.19.

Bis-[3-Ethyl-5-fluorobenzthiazole-(2)]trimethinecyanine iodide (X). 0.3 g of 2-methyl-5-fluorobenzthiazole ethiodide and 0.3 g of orthoformic ester were boiled for 20 minutes with 2 g of acetic anhydride. The precipitated dye was recrystallized from ethyl alcohol. Bronze needles with m.p. 288-289° with decomp. Absorption maximum, 562 mμ. Yield 0.15 g or 62 % of the theoretical.

Found %: I 24.32, 24.20. $C_{21}H_{19}N_2SF_2I$. Calculated %: I 24.05.

Bis-[3-Ethyl-5-fluoromethylbenzthiazole-(2)]-9-methyltrimethinecyanine iodide (XI). It was obtained from 0.5 g of 2-methyl-5-fluorobenzthiazole ethosulfate and 0.5 g of orthoacetic ester by heating for 30 min. with 3 g of pyridine and 3 drops of acetic anhydride. The ethiodide of the dye was precipitated with a solution of potassium iodide. Recrystallization from alcohol, the dye melted at 278-279° with decomp. Yield 0.15 g or 35% of the theoretical. Absorption maximum, 546 mμ.

Found %: I 23.14. $C_{22}H_{21}N_2S_2F_2I$. Calculated %: I 23.43.

Bis-[3-ethyl-5-flurobenzthiazole-(2)]-9-ethyltrimethinecyanine iodide (XII). 0.5 g of 2-methyl-5-fluorobenzthiazole ethosulfate and 0.5 g of orthopropionic ester were boiled for 40 minutes with 3 ml of acetic anhydride and 1 drop of pyridine. The dye was precipitated with ether from the solution, dissolved once more in a small amount of alcohol, and precipitated with potassium iodide. Yield after recrystallization from alcohol, 0.1 g or 23% of the theoretical; m.p. 255-256° with decomp. Absorption maximum, 550 mμ.

Found %: I 22.66. $C_{23}H_{23}N_2S_2F_2I$. Calculated %: I 22.84.

SUMMARY

1. Some 2-methyl-5-trifluoromethyl- and 2-methyl-5-fluorobenzthiazoles and their quaternary salts were synthesized.

2. Nine thiacyanine dyes with a trifluoromethyl group in position 5 and three thiacyanine dyes with a fluorine atom in position 5 were prepared.

3. It was shown that the introduction of a fluorine atom or a CF_3- group into position 5 of the thiacyanine has almost no effect on the position of the absorption maximum.

4. 2-Methyl-5-cyanobenzthiazole and 2-methylbenzthiazole-5-carboxylic acids were synthesized.

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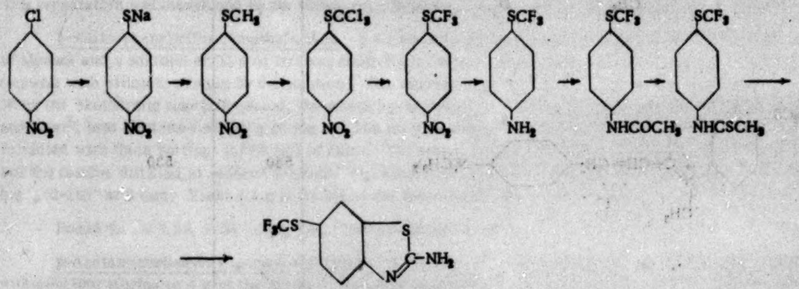
CYANINE DYES CONTAINING FLUORINE

III. CYANINE DYES FROM DERIVATIVES OF 6-TRIFLUOROMETHYLMERCAPTOBENZTHIAZOLE

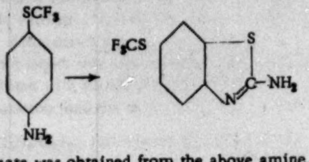
L. M. Yagupolsky and A. I. Kiprianov

The compounds containing a trifluoromethylmercaptan group, SCF_3, are poorly studied. The methods of preparation and the properties of the substances of this class are given only in the patent literature [1] and are mentioned in certain communications [2,3], on the chemistry of fluoro-organic compounds. Dyes containing the SCF_3-group, according to the results in the patents, are outstanding in stability to light and in the brightness of color. The effect the SCF_3-group, as a substituent, on the color of the dyes has not been investigated. A series of thiocyanine dyes containing a SCF_3-group in the 6-position of the benzthiazole nucleus was synthesized. As the starting materials, 2-amino- and 2-methyl-6-trifluoromethylmercaptobenzthiazole, not reported in the literature, were obtained. The latter compounds were synthesized according to the following scheme:

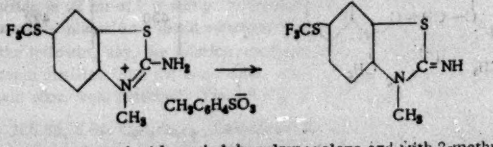


The methiodide of 2-methyl-6-trifluoromethylmercaptobenzthiazole and from it, the carbocyanine (I), the merocyanine (II), and the styryl dye (III) were prepared.

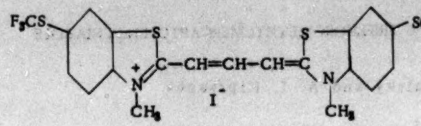
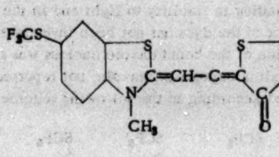
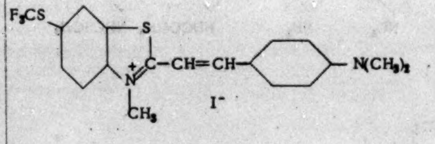
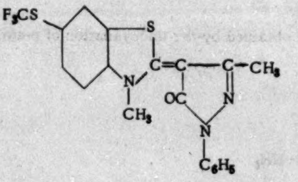
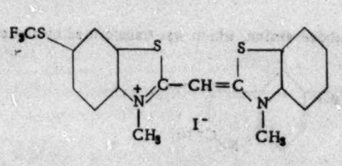
2-Amino-6-trifluoromethylmercaptobenzthiazole was obtained by the thiocyanation of p-aminophenyltrifluoromethylsulfide:



The p-toluenesulfonate was obtained from the above amine, which was transformed by the action of alkali into the imine:



The imine was condensed with methylphenylpyrazolone and with 2-methylbenzthiazole methylmethosulfate [4,5]; the common merocyanine (IV) and monomethinecyanine (V) were obtained. The structural formulas and the absorption maxima of the dyes obtained in alcoholic solutions are listed in the table; the absorption maxima of the corresponding dyes without SCF_3 groups are given there for comparison.

Expt. No.	Formula of dye	λmax (in mμ)	λmax of dye without SCF_3-group
I		565	557
II		550	556
III		540	530
IV		430	–
V		430	422

It is apparent from the table that the carbocyanine with the SCF_3-group as a substituent is colored somewhat more intensely than the unsubstituted dye. The preparation, containing the SCH_3-groups in the 6,6'-positions has an absorption maximum at 581 mμ [6]. Therefore, in cyanine dyes, the SCF_3-group is a weaker auxichrome than the SCH_3-group.

EXPERIMENTAL

p-Nitrophenylmethylsulfide was obtained by the methylation of sodium p-nitrothiophenolate. The latter was prepared from p-nitrochlorobenzene and Na_2S_2 [7]. The yield was 75% of the theoretical based on the p-nitrochlorobenzene used. The melting point of the product recrystallized from methyl alcohol was 72° [8].

p-Nitrophenyltrichloromethylsulfide. 16.5 g of p-nitrophenylmethylsulfide was dissolved in 40 ml of dry chloroform. The solution was cooled and dry chlorine was passed in for 1 hour in the light. The mixture was allowed to stand for 1 hour. The main part of the product crystallized. After the evaporation of the filtrate, some more of the product was obtained. The combined yield was 21.9 g or 81% of the theoretical, m.p. 92°. After recrystallization from acetone, m.p. 94°. This same melting point is reported in the communication of Zinke [9]; however, no details for the preparation of this substance are given.

p-Nitrophenyltrifluoromethylsulfide. A mixture of 12.5 g of p-nitrophenyltrichloromethylsulfide and 12 g of redistilled antimony trifluoride was placed in a Claisen flask and heated carefully with a naked flame until it melted. An exothermic reaction proceeded. As soon as the liquid started to boil, the flask was evacuated, and the distillation was continued until almost nothing distilled. The distillate was dissolved in a mixture of 50 ml of ether and an excess of 6 N HCl. The aqueous layer was separated, and the ether was washed several times with 6 N HCl until the wash liquid did not cloud up on dilution with water. The ether solution was dried over $MgSO_4$, the ether removed, and the residue vacuum distilled. p-Nitrophenyltrifluoromethylsulfide – a yellow liquid with b.p. 115° at 20 mm. Yield 7 g or 70% of the theoretical. The Beilstein test for halogen was negative. This preparation was mentioned in the patent [a]. Details of its preparation are not given in the patent.

p-Aminophenyltrifluoromethylsulfide. 6.4 g of p-nitrophenyltrifluoromethylsulfide was dissolved in 15 ml of alcohol and a solution of 34 g of stannous dichloride in 26 ml of concentrated hydrochloric acid was added stepwise with efficient stirring to the solution. The addition took 30 minutes. The temperature rose to 60-70°. When the exothermic reaction ceased, the solution was heated on the water bath for 30 minutes, then cooled and poured into a mixture of 120 g of ice and 100 ml of a 40% sodium hydroxide solution. The amine was extracted with three portions (of 35 ml) of ether. The ether solution was dried over $MgSO_4$, the ether removed and the residue distilled at reduced pressure. p-Aminophenyltrifluoromethylsulfide – a colorless liquid with b.p. 102-103° at 8 mm. Yield 4.7 g or 85.4% of the theoretical; n_D^{25} 1.5253.

Found %: N 7.29, 7.36. $C_7H_6NSF_3$. Calculated %: N 7.22.

p-Acetaminophenyltrifluoromethylsulfide. 2.3 g (10% excess) of acetic anhydride was added dropwise with efficient stirring to 4 g of the amine. The mixture solidified, and was recrystallized from dilute alcohol. Long white needles with m.p. 185°. Yield 4.55 g or 95% of the theoretical.

Found %: N 6.05, 6.10. $C_9H_8ONSF_3$. Calculated %: N 5.95.

p-Thioacetylaminophenyltrifluoromethylsulfide. 3.5 g of p-acetylaminophenyltrifluoromethylsulfide was dissolved in a mortar with 2 g of phosphorus pentasulfide and melted on the water bath under a layer of toluene for 20 minutes with efficient stirring. The toluene layer was then decanted, and the residue was twice extracted from 20 ml of hot toluene. After cooling, yellowish crystals of the thioacetyl derivative separated from the toluene solution. The mother liquor was concentrated. For purification, the precipitated crystals were dissolved in dilute alkali and precipitated with carbon dioxide. Yield 2.4 g, or 65% of the theoretical. Recrystallized from aqueous alcohol, the preparation had the m.p. 119°.

Found %: N 5.71. $C_9H_8NS_2F_3$. Calculated %: N 5.57.

2-Methyl-6-trifluoromethylmercaptobenzthiazole. A cooled solution of 1.7 g p-thioacetylaminophenyltrifluoromethylsulfide in 22 ml of 2 N sodium hydroxide was added dropwise with stirring to 25 ml of a 20% solution of potassium permanganate placed in a round bottomed flask. After mixing both solutions, the stirring was continued for 30 minutes. On the following day, the solution was poured from the settled yellow oil which was washed several times with water and steam distilled from the same flask. After recrystallization from petroleum ether, white needles, m.p. 74°, with a pleasant odor, were obtained. Yield 0.6 g, or 35% of the theoretical.

Found %: N 5.65, 5.82. $C_9H_6NS_2F_3$. Calculated %: N 5.62.

2-Methyl-6-trifluoromethylmercaptobenzthiazole methiodide was obtained by heating 0.6 g of the base and 0.3 g of dimethylsulfate on the boiling water bath for 3 hours. The product was washed with benzene, and precipitated from an aqueous solution with potassium iodide. After recrystallization from aqueous alcohol, the yield was 0.8 g of 85% of the theoretical; m.p. 244-245° with decomp.

Found %: I 32.25, 32.29. $C_{10}H_9NS_2F_3I$. Calculated %: I 32.49.

2-Amino-6-trifluoromethylmercaptobenzthiazole. A solution of 0.8 g of bromine in 4 ml of glacial acetic acid was added dropwise with stirring to a solution of 1 g of p-aminophenyltrifluoromethyl sulfide and 1.6 g of ammonium thiocyanate in 10 ml of 98% acetic acid. The mixture was stirred for 5 hours and filtered. The residue on the filter was washed with water. The filtrate and the wash water were neutralized with ammonia. The precipitate was filtered and dried. M.p. 148°. Yield 0.97 g or 75% of the theoretical. For analysis the product was dissolved in a small amount of alcohol and precipitated in the form of the hydrochloride salt by the addition of an equal volume of concentrated hydrochloric acid. The hydrochloride was dissolved in water, filtered, and the amine precipitated with ammonia. After 2 recrystallizations from aqueous alcohol, white crystals with m.p. 153-154° were obtained.

Found %: N 11.28, 11.36. $C_8H_5N_2S_2F_3$. Calculated %: N 11.20.

The acetyl derivative was obtained by heating 1 g of the amine and 0.5 g of acetic anhydride in 5 ml of xylol to boiling for 3 hours. The product which crystallized upon cooling, was recrystallized from alcohol; m.p. 214-215°. Yield 1.04 g or 90% of the theoretical.

Found %: N 9.56, 9.60. $C_{10}H_7ON_2S_2F_3$. Calculated %: N 9.58.

2-Amino-6-trifluoromethylmercaptobenzthiazole p-toluenesulfonate was obtained by melting 0.27 g of 2-amino-6-trifluoromethylmercaptobenzthiazole with 0.22 g methyl p-toluenesulfonate for 30 minutes at 140° on the oil bath. The product, washed with benzene, was recrystallized from 8 ml of water. White long needles with m.p. 259-260°. Yield 0.38 g of 79.5% of the theoretical.

Found %: N 6.61. $C_{16}H_{15}O_3N_2S_3F_3$. Calculated %: N 6.45.

6-Trifluoromethylmercapto-N-methylbenzthiazolonimine. 0.38 g of 2-amino-6-trifluoromethylmercaptobenzthiazole p-toluenesulfonate was dissolved in 10 ml of water and 2 N alkali was added stepwise to the warm solution until alkaline to litmus. The imine came out in the form of yellow, finely crystalline powder. Yield 0.18 g or 78% of the theoretical. After recrystallization from petroleum ether, m.p. 94°.

Found %: N 10.73, 10.76. $C_9H_7N_2S_2F_3$. Calculated %: N 10.60.

DYES

Bis-[3-methyl-6-trifluoromethylmercaptobenzthiazole-(2)]-trimethinecyanine iodide (I). 0.3 g of 2-methyl-6-trifluoromethylmercaptobenzthiazole and 0.3 g of orthoformic ester were boiled with 3 ml of acetic anhydride for 45 minutes. Yield, after recrystallization from alcohol, 0.15 g or 60% of the theoretical. Absorption maximum 565 mμ. Violet needles, m.p. 270-271° with decomp.

Found %: I 18.84, 18.90. $C_{21}H_{15}N_2S_4F_6I$. Calculated %: I 19.12.

2-(3'-Methyl-6'-trifluoromethylmercaptobenzthiazolenylidene-2-ethylidene)-3-oxo-2,3-dihydrothionaphthene (II). 0.25 g of 2-methyl-6-trifluoromethylmercaptobenzthiazole methiodide, 0.16 g of 3-hydroxythionaphthene-2-aldehyde anil, and 0.2 g of anhydrous sodium acetate were heated for 45 minutes with 4 ml of absolute alcohol. The precipitate was washed with water and recrystallized from alcohol. Red-violet needles with m.p. 298-300° with decomp. Yield 0.14 g or 51.8% of the theoretical. The preparation exhibits solvatochromatism. Its absorption maximum in alcohol solution was 550 mμ, and in benzene, 525 mμ.

Found %: N 3.19, 3.26. $C_{19}H_{12}ONS_3F_3$. Calculated %: N 3.31.

2-p-Dimethylaminostyryl-6-trifluoromethylmercaptobenzthiazole methiodide. 0.25 g of 2-methyl-6-trifluoromethylmercaptobenzthiazole methiodide and 0.1 g of p-dimethylaminobenzaldehyde were boiled with 3 ml of acetic anhydride for 45 minutes. The precipitated dye was recrystallized from alcohol. Long red-violet needles with m.p. 235-236° with decomp. Yield 0.23 g or 70% of the theoretical. Absorption maximum 540 mμ.

Found %: I 22.11, 22.17. $C_{19}H_{18}N_2S_2F_3I \cdot C_2H_5OH$. Calculated %: I 22.36.

According to analysis the dye contains 1 molecule of alcohol of crystallization.

4-(3-Methyl-6'-trifluoromethylmercaptobenzthiazolenylidene-(2')-(1-phenyl-3-methylpyrazolone-5)(IV). 0.16 g of 6-trifluoromethylmercapto-N-methylbenzthiazolonimine and 0.12 g of 1-phenyl-3-methylpyrazolone-5 were melted together for 30 minutes at 150° under a water vacuum. The reaction product was dissolved in alcohol by heating, filtered, cooled, and the precipitated dye recrystallized from alcohol once more. Yellow needles. Yield 0.18 g or 64% of the theoretical; m.p. 174-175°.

Found %: N 10.02, 10.14. $C_{19}H_{14}ON_3S_2F_3$. Calculated %: N 10.00.

3-Methyl-6-trifluoromethylmercaptobenzthiazole-(2)-3-methylbenzthiazole(2')-methinecyanine iodide (V). 0.1 g of 6-trifluoromethyl-N-methylbenzthiazolonimine and 0.12 g of 2-methylbenzthiazole methylmethasulfate were melted together for 15 minutes at 175° under water pump vacuum. Toward the end of the reaction, the melt stopped foaming and solidified. The reaction product was washed several times with acetone. The dye was dissolved in alcohol, its iodide precipitated with potassium iodide, and then washed with water on the filter and recrystallized from 60 ml of alcohol. Yellow needles. Yield 0.12 g or 60% of the theoretical; m.p. 263-264° with decomp.

Found %: I 23.29, 23.37. $C_{18}H_{14}N_2S_3F_3I$. Calculated %: I 23.60.

SUMMARY

1. 2-Methyl- and 2-amino-6-trifluoromethylmercaptobenzthiazole and a series of intermediate products, necessary for their preparation, were synthesized.

2. The quaternary salts of the above bases and the 5-thiacyanine dyes containing a SCF_3-group in the 6-position of the benzthiazole nucleus were obtained.

3. The SCF_3-group as a substituent in cyanine dyes is a weaker auxichrome than the SCH_3-group.

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[illegible] (V). [illegible] g of [illegible] and [illegible] g of [illegible] were heated for [illegible] minutes at [illegible] under water pump vacuum. Toward the end of the reaction, [illegible]. The reaction product was washed several times with alcohol. The dye was dissolved in [illegible], [illegible] precipitated with [illegible], and then washed with water on the filter and [illegible] from [illegible] ml of alcohol. Yellow needles. Yield [illegible] g ([illegible] of the theoretical), m.p. [illegible] with decomp.

Found %: [illegible]. Calculated %: [illegible].

SUMMARY

1. 2-Methyl- and [illegible]-6-trifluoromethyl[illegible]benzothiazole and a series of intermediate products, necessary for their preparation, were synthesized.

2. The [illegible] dyes of the above bases and [illegible] containing a [illegible] group in the 6-position of the benzothiazole nucleus were obtained.

3. The NCF_3 group as a substituent in cyanine dyes is a weaker [illegible] than the CF_3 group.

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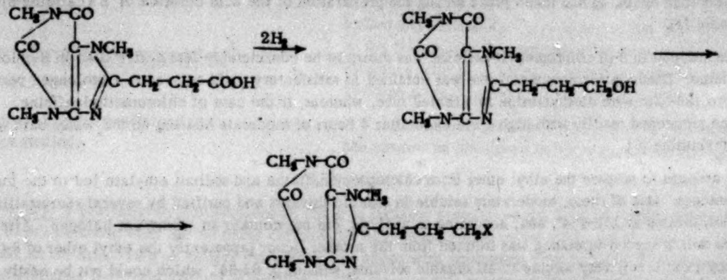
8- SUBSTITUTED DERIVATIVES OF METHYLATED XANTHINES

IV. 8-(3-HYDROXYPROPYL)-CAFFEINE

E. S. Golovchinskaya and E. S. Chaman

The starting material for the synthesis of 8-(3-hydroxypropyl)-caffeine was β-(caffeine-8)-propionic acid [1] which was reported in the previous communication. Further transformations of 8-(3-hydroxypropyl)-caffeine resulting from the reduction of this acid, created a possibility for obtaining an entire group of caffeine derivatives substituted in position 8 with a three-membered hydrocarbon residue:



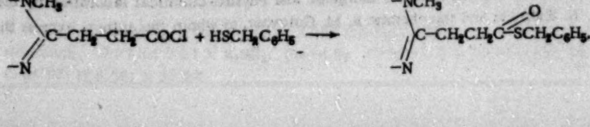
X = halide, NR_2, H, OCOR, OR, and others.

The choice of a method for reducing β-(caffeine-8)-propionic acid into 8-(3-hydroxypropyl)-caffeine was for the most part limited by the chemical properties of caffeine. Its sensitivity to alkalies exempted the use of the reduction reaction with sodium in alcohol which is widely applied in similar cases in laboratory practice. The tendency of xanthines to be transformed into desoxyxanthines during electrochemical reduction [2], as well as the hydrogenation of the ring during catalytic reduction of the carbonyl group which needs high temperature and pressure, did not permit the use of these two convenient methods for the transformation of acids into derivatives of the corresponding alcohols.

In view of the problem posed in the present investigation, the reduction of β-(caffeine-8)-propionic acid, the method of Prelog et al [3] published in 1946 for the preparation of alcohols from esters of certain thiolcarboxylic acids by means of reductive desulfurization with large excess of Raney nickel in dry solvent media at room temperature, became of great interest. The results of these authors appeared to conflict, without reason, with results published almost at the same time in the communication of Wolfram and Carabinos [4] reporting the production of aldehydes, not alcohols from thiolcarboxylic esters under analogous conditions differing only in the use of 70-80% alcohol, instead of a dry solvent, higher reaction temperatures (70-80°), and a smaller amount of Raney nickel.

The attempted application of the reductive desulfurication had beside the main task, the preparation of 8-(3-hydroxypropyl)-caffeine, two more: to clarify the possibility of extending this reaction to a series of (caffeine-8)-alkylcarboxylic acid, and to study the question of which variation in the conditions of reduction determines the formation of the alcohol and the aldehyde.

The thiol ester of β-(caffeine-8)-propionic acid used as the starting material was the benzyl ester. It was obtained in good yield by the reaction of the acid chloride with benzyl mercaptan.



Experiments on the reduction of this ester under various conditions gave identical results. Whether the ester was stirred for 2 hours in absolute dioxane solution with 12 parts by weight of Raney nickel without heating, or heated for 16 hours with 5 parts of Raney nickel in 80% alcohol solution, only one substance was obtained, m.p. 89-91°, crystallizing from ethyl acetate as fine needles.

The same substance, but in a mixture with the unreacted starting material, was obtained in a reaction with a smaller amount (2.5 parts by weight) of Raney nickel. This substance, as shown by analysis as well as chemical properties, was 8-(3-hydroxypropyl)-caffeine. Caffeine-8-propionaldehyde was not obtained in any of the experiments conducted. Upon the study of the mother liquor after the separation of 8-hydroxypropylcaffeine, not even traces of the aldehyde could be detected by qualitative reactions. From these solutions, in all of the experiments conducted, i.e., under various reduction conditions, a crystalline substance with m.p. 186-187° was isolated, which on further study, was shown to be 8-ethylcaffeine [5].

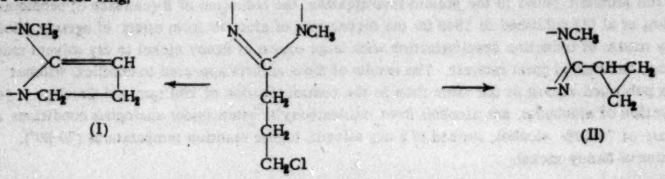
8-(3-Hydroxypropyl)-caffeine, obtained in the above reduction reactions, was characterized by the formation of an acetate. 8-(3-chloropropyl)-caffeine was also obtained from it by heating with thionyl chloride in absolute benzene. The use of an excess of thionyl chloride in this case, did not lead to further chlorination of the hydrocarbon chain, as had taken place during the preparation of the acid chloride of β-(caffeine-8)-propionic acid [1].

The halogen in 8-(3-chloropropyl)-caffeine was shown to be considerably less active than in 8-chloromethylcaffeine. Diethylaminopropylcaffeine was obtained in satisfactory yield only after a prolonged period of heating to 120-130° with diethylamine in a sealed tube, whereas, in the case of chloromethylcaffeine, this reaction proceeded readily with high yield even after 4 hours of moderate heating on the water bath with excess diethylamine [6].

An attempt to prepare the ethyl ether from chloropropylcaffeine and sodium ethylate led to the formation of two substances. One of these, moderately soluble in organic solvents and purified by several recrystallizations from alcohol, melted at 172-174°, and, according to analysis, did not contain an ethoxyl or halogen. After its recrystallization, a second substance was isolated from the mother liquor [apparently the ethyl ether of 8-(3-hydroxypropyl)-caffeine], very soluble in all organic solvents, with m.p. 82-84°, which could not be easily purified to give a satisfactory analysis because of its great solubility. The results of the elementary analysis for this substance with m.p. 172-174° almost coincided with those calculated for 8-propylcaffeine. On the other hand, this substance was sharply differentiated from 8-propylcaffeine [previously synthesized by one of the authors [7]],by its melting point (m.p. of 8-propylcaffeine, 116-117°) and other properties.

The absence of a double bond in the side chain, shown by the reactions – attempts at hydrogenation, oxidation with $KMnO_4$, and addition of bromine- excluded the plausible hypothesis of the cleavage to form 8-allylcaffeine.

Two other possibilities, the elimination of the hydrogen chloride accompanied by the closing of a five or three membered ring,



were examined by comparing the ultra-violet absorption spectra of the compound obtained, 8-propylcaffeine, and caffeine (See Figure 1•). This comparison showed that although the maximum in the absorption spectrum of the substance studied is shifted toward the longer wavelengths by 50 A, and the intensity of absorption 1.5 times in comparison to the spectrum of caffeine), the general character of the spectrum of each of the three substances differs little. The resemblance of the spectra of these compounds excluded the possibility of the closing of a five membered ring. The formation of a complex three membered ring system (II) accompanied by a rearrangement

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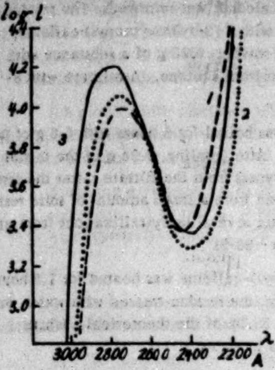
• The spectral analysis of this compound was made in the Inorganic and Physico-chemical laboratory by the senior scientific technician Yu. N. Sheinker and the chemist B. M. Golovner, to whom the authors express their sincere appreciation.

of the double bond from the imidazole part of the molecule to the side chain would have caused a much more significant change in the absorption spectrum.

The observed insignificant differences between the spectrum of the substance investigated and that of the other derivatives of caffeine, does not exclude the formation of a double bond in the propyl residue or the formation of a three membered ring (II). The absence of a double bond, shown by the chemical reactions of the substance, combined with the ultra violet absorption spectrum, results, of analysis, and other properties, gave a basis for considering that it was probably 8-cyclopropylcaffeine (II).

For the final proof that the substance obtained as a result of the reduction of the thiol ester of β-(caffeine-8)-propionic acid was 8-(3-hydroxypropyl)-caffeine, it was transformed into 8-propylcaffeine. Its chloroderivative was dehydrohalogenated by heating with an excess of Raney nickel in alcoholic solution in the presence of an equimolecular amount of alkali (8). A substance with m.p. 116-117° identical with the 8-propylcaffeine present for comparison was obtained.

The authors gratefully thank Prof. O. Yu. Magidson for the interest he has shown in the above investigation.



1) Caffeine; 2) propylcaffeine; 3) substance studied.

EXPERIMENTAL

Benzyl β-(caffeine-8)-thiolpropionate. 30 g of caffeine propionic acid, 15 g of thionyl chloride, and 200 ml of dry benzene were stirred under reflux until complete solution of the acid, and the heating was continued for 30 min. 26 g of benzyl mercaptan was added with continuous stirring to the cooled reaction mixture, and after 5-10 min., 30 ml of pyridine. The reaction was continued for 24 hours at room temperature. The precipitate was filtered, washed with cold benzene, water, and ether. Weight 9 g; m.p. 126-127°. The benzene and pyridine were removed in vacuum from the solution. The residue was treated with ether. The crystals were filtered, washed with ether, and cold acetone. Weight 25.3 g, m.p. 124-126°. The combined yield of the ester was 34.3 g which corresponds to 81.6% of the theoretical. White oily needles, m.p. 126-127° readily soluble in the cold in chloroform, dioxane, and benzene. The ester is recrystallizable from ethyl alcohol – 1:40, acetone – 1:5, methyl ethyl ketone – 1:7; it is insoluble in water and ether.

6.324 mg substance: 6.73 ml 0.01 N H_2SO_4. 5.761 mg substance: 6.12 ml 0.01 N H_2SO_4. Found %: N 14.90, 15.06. $C_{18}H_{20}O_3N_4S$. Calculated %: N 15.05.

8-(3-Hydroxypropyl)-caffeine. 1.) 30 g of Raney nickel was added to a solution of 5 g of benzyl-β-(caffeine-8)-thiolpropionate in 50 ml of dry dioxane, and the mixture stirred for 2 hours. An increase of 10-12° in temperature occurred. The settled solution was decanted, and the catalyst washed 3-4 times with dioxane. The dioxane was removed from the combined solutions, and the viscous residue crystallized by the addition of 1.5-2 ml of cold ethyl acetate. Recrystallized from ethyl acetate. Weight 1.7 g which corresponds to 55% of the theoretical. White needles with a faint pearly sheen, m.p. 88-91°, readily soluble in cold dioxane, acetone alcohol, and chloroform. Recrystallizable from benzene – 1:10, ethyl acetate – 1:5. It crystallized from xylol in the form of chains of needles.

5.502 mg substance: 8.57 ml 0.01 N H_2SO_4. 5.628 mg substance: 8.77 ml 0.01 N H_2SO_4. 4.639 mg substance: 8.789 mg CO_2; 2.800 mg H_2O. 3.176 mg substance: 6.022 mg CO_2; 1.912 mg H_2O. Found %: C 51.66, 51.71; H 6.75, 6.73; N 21.81, 21.81. $C_{11}H_{16}O_3N_4$. Calculated %: C 52.39.; H 6.35; N 22.22.

The ethyl acetate was completely removed from the filtrate, after the removal of the hydroxylpropylcaffeine, and the residue cooled. Cyrstals separated which, after recrystallization from acetone, melted at 186-187°.

4.164 mg substance: 8.347 mg CO_2; 2.356 mg H_2O. 4.968 mg substance: 8.88 ml 0.01 N H_2SO_4. 5.038 mg substance: 9.07 ml 0.01 N H_2SO_4. Found %: C 54.67; H 6.33; N 25.02, 25.20. $C_{10}H_{14}O_3N_4$. Calculated %: C 54.05; H 6.36; N 25.22.

Mixed m.p. determination with 8-ethylcaffeine – 186-187°.

2.) A solution of 3.4 g of benzyl β-(caffeine-8)-thiolpropionate in 136 ml of 80% alcohol was boiled with 17 g of Raney nickel for 6 hours on the water bath. It was filtered, and the alcohol was removed. The residue, after recrystallization from ethyl acetate, was 1.05 g; m.p. 79-81°. Mixed with 8-(3-hydroxypropyl)-caffeine, it melted at 79-81°. From the ethyl acetate filtrate, after the removal of the solvent, 0.25 g of a substance with m.p. 134-171° was obtained which melted at 184-186° after recrystallization from acetone. A mixture with 8-ethylcaffeine melted at 184-186°.

3.) A solution of 2.5 g of the thiol ester in 100 ml of 80% alcohol was boiled for 6 hours with 6.5 g of Raney nickel. It was filtered, and the alcohol removed to a volume of 13-15 ml. After cooling, 0.35 g of the initial thiol ester with m.p. 122-124° precipitated. The solvent was removed to dryness from the filtrate, after the removal of the unreacted ester, the residue treated with hot ethyl acetate, and filtered from a small amount of solid residue. The residue, after the removal of the ethyl acetate – 0.8 g, m.p. 63-73°; after several recrystallizations from ethyl acetate, it melted at 88-90°. Mixed m.p. with 8-(3-hydroxypropyl)-caffeine – 88-91°.

Acetate of 8-(3-hydroxypropyl)-caffeine. 0.55 g of 8-(3-hydroxypropyl)-caffeine was heated for 1.5 hours with 3 g of acetic anhydride. The acetic anhydride was removed in vacuum, the residue treated with water, and neutralized with dry sodium bicarbonate. Wt. 0.6 g; m.p. 136-138°. Yield 93.7% of the theoretical. White needles recrystallizable from ethyl acetate, alcohol, and benzene; insoluble in water.

6.659 mg substance: 9.00 ml 0.01 N H_2SO_4. 6.707 ml substance: 9.04 ml 0.01 N H_2SO_4. Found %: N 18.92, 18.87. $C_{13}H_{18}O_4N_4$. Calculated %: N 19.04.

8-(3-Chloropropyl)-caffeine. A solution of 5.5 g of hydroxypropylcaffeine in 60 ml of absolute benzene was heated for 6 hours with 3 ml of thionyl chloride. The benzene was removed, and the residue treated with cold sodium bicarbonate solution. The filtered substance was recrystallized from ethyl acetate. Weight – 3.6 g which corresponds to 62% of the theoretical. Transparent light greenish-yellow prisms with m.p. 117-118°, readily soluble in the cold in benzene and ether. It crystallized from alcohol as coarse platelets, ethyl acetate – transparent, coarse crystals.

4.327 mg substance: 2.314 mg AgCl. 5.437 mg substance: 2.872 mg AgCl. Found %: Cl 13.23, 13.07. $C_{11}H_{15}O_2N_4Cl$. Calculated %: Cl 13.12.

8-(3-Diethylaminopropyl)-caffeine. 3 g of 8-chloropropylcaffeine was heated for 12 hours in a closed tube with 30 ml of freshly distilled diethylamine at 120-130° bath temperature. After cooling, the diethylamine hydrochloride was filtered off, and the excess diethylamine removed in vacuum. The residue, a yellow oil, was dissolved in ether, filtered, and the diethylaminopropylcaffeine hydrochloride precipitated by the addition of an alcoholic hydrogen chloride solution until acid on Congo. It was recrystallized from absolute alcohol. Weight 2.5 g which corresponds to 66% of the theoretical.

Transparent, scaly platelets with m.p. 236-238°, readily soluble in water, and insoluble in organic solvents.

5.882 mg substance: 2.430 mg AgCl. 6.452 mg substance: 2.666 mg AgCl. Found %: Cl 10.22, 10.22. $C_{15}H_{25}O_2N_5 \cdot HCl$. Calculated %: Cl 10.33.

The 8-diethylaminopropylcaffeine base was liberated from an aqueous solution of the hydrochloride with 26% alkali solution, and extracted with ether. After the removal of the ether, the crystallized residue was recrystallized from pentane. White, light needles with m.p. 72-74°; readily soluble in cold alcohol, ether, chloroform, benzene, and water.

5.604 mg substance: 7.43 ml 0.01 N H_2SO_4. 4.498 mg substance: 7.24 ml 0.01 N H_2SO_4. Found %: N 22.59, 22.53. $C_{15}H_{25}O_2N_5$. Calculated %: N 22.80.

8-Propylcaffeine. A solution of 0.3 g of 8-chloropropylcaffeine and 0.07 g of potassium hydroxide in 4 ml of 80% alcohol was heated with 3 g of Raney nickel for 4 hours on the boiling water bath. 0.25 g of 8-propylcaffeine, with m.p. 105-106° was isolated from the filtered solution after removal of the alcohol. After recrystallization from methyl alcohol, m.p. 114-115°. After one more recrystallization, m.p. 116-117°. Mixed with 8-propyl caffeine, it melted at 116-117°.

Heating of 8-(3-chloropropyl)-caffeine with sodium ethylate. 1 g of chloropropylcaffeine was added to a solution of 0.09 g of Na in 20 ml of alcohol (99.7%), and the mixture boiled for 4 hours. The alcohol was removed, and the residue treated with ether. Insoluble in ether, 0.35 g with m.p. 165-167°. After several recrystallizations from methyl alcohol, m.p. 172-174°. Coarse needles, readily soluble in benzene, ethyl alcohol, and chloroform; slightly soluble in ether, and insoluble in pentane.

4.349 mg substance: 7.40 ml 0.01 N H_2SO_4. 4.620 mg substance: 7.91 ml 0.01 N H_2SO_4. 3.459 mg substance: 7.162 mg CO_2; 1.801 mg H_2O. 0.1909 g substance: 15.2694 g benzene: Δt 0.27°. Found %: C 56.46; H 5.82; N 23.82, 23.97. M 237.57. $C_{11}H_{14}O_2N_4$ (caffeine-cyclopropane). Calculated %: C 56.17; H 6.37; N 23.74. M 234.1.

0.5 g of a white substance which had the m.p. 82-84° after 4 recrystallizations from a mixture of carbon tetrachloride and pentane, was isolated from the ether solution. Readily soluble in ether, benzene, alcohol, ethyl acetate, acetone, methyl ethyl ketone, chloroform, and carbon tetrachloride.

5.476 mg substance: 6.61 ml 0.01 N H_2SO_4. 3.695 mg substance: 5.41 ml 0.01 N H_2SO_4. 3.832 mg substance: 2.91 ml $^1/_{50}$ N $Na_2S_2O_3$. Found %: N 20.67, 20.49; C_2H_5O 11.40. $C_{13}H_{20}O_3N_4$ [8-(3-ethoxypropyl)-caffeine]. Calculated %: N 20.00; C_2H_5O 16.07.

SUMMARY

1. The reductive desulfurization reaction of thiolcarboxylic esters with Raney can be applied to (caffeine-8)-alkylcarboxylic acids.

2. The final result of the reductive desulfurization reaction of benzyl β-(caffeine-8)-thiolpropionate with Raney nickel was the alcohol, not the aldehyde.

3. Benzyl β-(caffeine-8)-thiolpropionate, 8-(3-hydroxypropyl)-caffeine, 8-(3-chloropropyl)-caffeine, the acetate of 8-(3-hydroxypropyl)-caffeine, and 8-(3-dimethylaminopropyl)-caffeine (hydrochloride and base) were synthesized and reported.

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* See Consultants Bureau English translation, p. 593.

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8-SUBSTITUTED DERIVATIVES OF METHYLATED XANTHINES

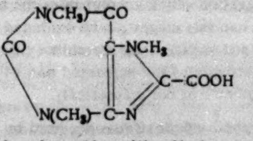
V. REDUCTIVE DESULFURIZATION OF CAFFEINE 8-CARBOXYLIC ACID THIOL ESTERS

E. S. Golovchinskaya and E. S. Chaman

In the previous communication [1], the reductive desulfurization of benzyl β-(caffeine-8)-thiolpropionate by the action of Raney nickel was reported. The final result of this reaction was shown to be 8-(3-hydroxypropyl)-caffeine. As the side product, independent of the temperature, the absence or presence of moisture, and the amount of Raney nickel used, 8-ethylcaffeine was invariably isolated. The formation of 8-caffeinepropionaldehyde was not detected in any of the experiments conducted.

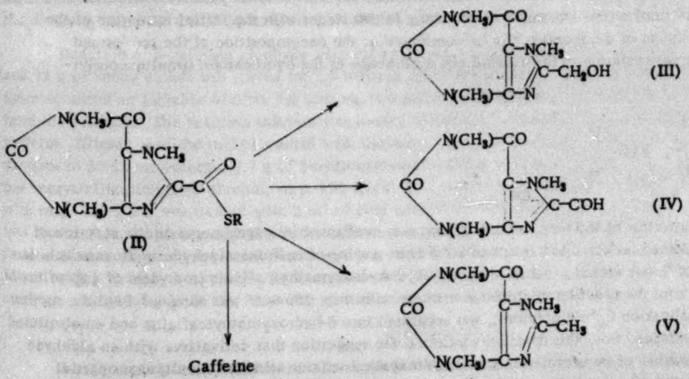
The study of this reaction with other examples of caffeine derivatives substituted by the thiolcarboxylic group in position 8, was undertaken in order to elucidate in more detail the process of reductive desulfurization, and in particular, to explain the reason for the elimination of the entire thiolcarboxylic group leading to the formation of a compound with a shorter hydrocarbon chain.

Caffeine 8-carboxylic acid (1) served as the starting material for this investigation.



(I)

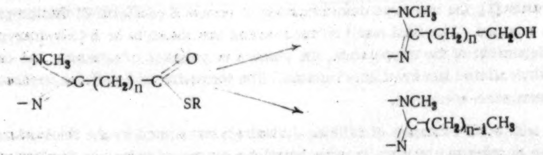
In spite of the fact that the acid readily eliminates carbon dioxide in contrast to the very stable β-(caffeine-8)-propionic acid, it was used as the model for a detailed study of the reductive desulfurization because known compounds, which have been previously synthesized by one of us, and are available for comparison, would be formed as a result of any reduction of its thiol ester (II) – 8-hydroxymethylcaffeine (III), 8-caffeinealdehyde (IV) as well as 8-methylcaffeine (V), and caffeine.



Benzyl caffeine-8-thiolcarboxylate was obtained, as was the ester of caffeine thiolpropionate, by the reaction of the acid chloride with benzyl mercaptan.

The reduction reaction of benzyl caffeinethiolcarboxylate, which was effected by means of 12 parts by weight of Raney nickel in dry dioxane medium, led to the formation of a mixture of two substances. A small amount of a substance, poorly soluble in cold chloroform with m.p. 224° identified as 8-hydroxymethylcaffeine and the main product of the reaction, which was very soluble in chloroform, unsubstituted caffeine, were isolated from the mixture. Pure caffeine, in a yield of 89% of the theoretical, was obtained upon heating the thiolester with 6 parts by weight of Raney nickel in an 80% alcohol medium. 8-Hydroxymethylcaffeine could not be detected in this reaction. As with the reduction of the thiol ester of caffeine propionic acid, no traces of the aldehyde could be detected in the reaction mixtures of any of the reduction reactions.

The formation of 8-ethylcaffeine upon the reduction of the thiol ester of the very stable β-(caffeine-8)-propionic acid, and caffeine upon the reduction of the readily decarboxylated caffeine-8-carboxylic acid, showed that a reaction leading to the shortening of the hydrocarbon chain by one carbon atom takes place at the same time as the reductive desulfurization leading to the formation of the corresponding alcohols upon the action of the Raney nickel.

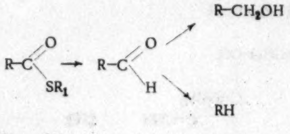


The second reaction, as a rule, apparently accompanies the reduction of the thiol ester of caffeine carboxylic acids wherein, in its role as the main or side product depends on the stability of the acid used.

The results obtained from two examples of caffeine carboxylic acids do not give any basis for supposing that the observed elimination is the usual reaction which accompanies the reductive desulfurization of thiol esters of all acids by the action of Raney, nor can this suggestion be excluded because, in the articles cited in the previous communication by Prelog et al, and Wolfram and Carabinos [2] on the reductive desulfurization of thiol esters, there is no mention made of the recovery of the unreacted part of the starting ester while the yields obtained are not always satisfactory (from 22-60% of the theoretical).

The suggestion that the formation of caffeine and 8-ethylcaffeine occurred by the decomposition of the alcohol formed initially and, therefore, is a secondary reaction, was completely refuted by the experiment in which 8-hydroxymethylcaffeine was reacted for 2 hours with Raney nickel: 8-hydroxymethylcaffeine was recovered almost quantitatively from the reaction mixture. This process was also contradicted by the fact that, when the time of the reduction of thiol esters was increased, not even in one case did the process shift toward a decrease in the yield of the alcohol with a corresponding increase in the amount of the cleavage product.

If the reduction of thiol esters is pictured as occurring in two stages with the initial formation of the aldehyde, then the mechanism of the reaction can be considered as the decomposition of the pre-formed aldehyde, undergoing a transformation to the alcohol and a cleavage to the hydrocarbon simultaneously:



The validity of this view of the reaction mechanism was confirmed by experiments on the reaction of 8-caffeinealdehyde with Raney nickel. As a result of a 2.5 hour stirring of caffeine aldehyde in dioxane solution with 12 parts by weight of Raney nickel at room temperature, 8-hydroxymethylcaffeine in a yield of 40% of the theoretical was isolated from the reaction mixture. A mixture with m.p. 185-205° was obtained from the mother liquor, which by recrystallization from chloroform, was separated into 8-hydroxymethylcaffeine and unsubstituted caffeine. The caffeine obtained from this reaction confirmed the suggestion that derivatives with an aldehyde group in position 8 are capable of transformation into 8-hydroxyalkylcaffeine with the simultaneous partial cleavage. The probability is also strengthened that the reduction of caffeine-8-carboxylic esters occurs by means of a stage in which the aldehyde is formed, and that the initially formed aldehyde compounds, as intermediates, decompose and serve as a source of the compounds with the shortened hydrocarbon chain.

The authors express their sincerest gratitude to the director of the laboratory in which this investigation was conducted, Prof. O. Yu. Magidson.

EXPERIMENTAL

Preparation of 8-caffeinecarboxylic acid chloride. 5 g of 8-caffeinecarboxylic acid and 6 ml of thionyl-chloride were heated for 6 hours at a bath temperature of 82-85°. The excess thionyl chloride was removed in vacuum, and the residue recrystallized once from dry benzene. Weight 2.5 g, m.p. 168-173°. Yellow crystals which clung to the walls of the crystallization flask[*].

Benzyl 8-caffeinethiolcarboxylate. A solution of 1.5 g of unpurified caffeine carboxylic acid chloride in 20 ml of dry benzene was added dropwise with stirring in 5-10 min. to a solution of 2.2 g of benzyl mercaptan and 0.7 g of dry pyridine in 5-10 ml of dry benzene. The reaction mixture was stirred for 20 hours. The combined reaction time was 48 hours at room temperature. It was filtered, and the residue, a mixture of pyridine hydrochloride and the thiol ester, was washed with water and ether. Weight 0.8 g, m.p. 173-175° Another 0.2 g of the thiol ester with m.p. 174.5-176° was isolated from the benzene solution. The combined yield was 1 g which corresponds to 50% of the theoretical based on the acid chloride used. Colorless, transparent prisms with m.p. 175-176°. The ester is readily soluble in the cold in chloroform and dioxane. It was recrystallizable from ethyl alcohol – 1:60, isopropyl alcohol – 1:70, butyl alcohol – 1:20, benzene 1:10; it was slightly soluble in ether and insoluble in water.

6.90 mg substance: 4.645 mg $BaSO_4$. 6.570 mg substance: 4.390 mg $BaSO_4$. 5.952 mg substance: 7.03 mg 0.01 N H_2SO_4 Found %: S 9.24, 9.17; N 16.53. $C_{16}H_{16}O_3N_4S$. Calculated %: S 9.32; N 16.28.

Reaction of benzyl 8-caffeine thiolcarboxylate with Raney nickel. 1) A solution of 1.5 g of benzyl 8-caffeinethiolcarboxylate in 15 ml of dry dioxane was stirred for 2 hours at room temperature with 18 g of Raney nickel (an increase of 9° in the temperature occurred). The residue, after filtration and removal of the dioxane, 0.7 g with m. p. 169-203°, was treated with 3 ml of cold chloroform and filtered. 0.1 g with m.p. 219-224° was filtered off. Mixed with 8-hydroxymethylcaffeine, it melted at 219-225°. 0.1 g of the substance with m.p. 219-224° was heated with thionyl chloride. After removal of thionyl chloride, it melted at 201-209°. After recrystallization from ethyl acetate, m.p. 208-211°. Mixed with 8-monochloromethylcaffeine, it melted at 212-214°.

2) A solution of 1 g of benzyl 8-caffeinethiolcarboxylate in 50 ml of 80% alcohol and 6 g of Raney nickel was heated for 5 hours on the water bath. The alcohol was removed from the filtered solution; the residue melted at 226-230°; melting point of a mixture with caffeine, 226-231°. Yield 0.56 g which corresponds to 89% of the theoretical.

Reaction of 8-hydroxymethylcaffeine with Raney nickel. 1 g of 8-hydroxymethylcaffeine was stirred with 50 ml of dry dioxane. A large part of the substance went into solution at room temperature. 10 g of Raney nickel was added. The stirring was continued for 2 hours, after which time, it was heated until complete solution of the 8-hydroxymethylcaffeine, filtered, and the catalyst washed with hot dioxane. The residue, after the removal of the dioxane, was 0.90 g of 8-hydroxymethylcaffeine with m.p. 222-224°.

Reaction of 8-caffeine aldehyde with Raney nickel. A solution of 8-caffeine aldehyde in 50 ml of dioxane and 12 g of Raney nickel was stirred for 2.5 hours at room temperature. Upon the addition of the Raney nickel, there occurred an increase of 5° in the temperature and a slow separation of crystals of 8-hydroxymethylcaffeine from the solution. The reaction mixture was heated to complete solution of the precipitated 8-hydroxymethyl caffeine, filtered, and the nickel washed with dioxane. From the combined dioxane solution, concentrated in vacuum to 20-25 ml volume, 0.4 g of 8-hydroxymethylcaffeine with m.p. 214-221° crystallized on cooling. After one recrystallization from alcohol, m.p. 223-224°. The residue from the final removal of the dioxane, 0.35 g with m.p. 185-205°, was treated with 2 ml of cold chloroform and 0.05 g more of a substance was isolated, which was shown to be 8-hydroxymethylcaffeine with m.p. 214-218° after one recrystallization from alcohol. The residue after removal of the chloroform, with m.p. 211-230°, was recrystallized from alcohol; m.p. 221-230°. Mixed with 8-hydroxymethylcaffeine, it melted at 176-185° with 8-caffeine aldehyde – 135-160°, and with caffeine – 227-230°. After two more recrystallizations from alcohol, m.p. 227-231°.

SUMMARY

1. The reductive desulfurization reaction of thiol esters of caffeine-8-carboxylic acid in primary alcohols with Raney nickel, is accompanied by the formation of compounds in which the side chain is shortened by one carbon atom.

2. Derivatives of caffeine substituted in position 8 by an aldehyde residue, are transformed partially into

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[*] Upon attempts to recrystallize further the acid chloride for analysis, a hydrolysis occurred; for this reason the preparation of the thiol ester was effected with unpurified acid chloride.

alcohols and partially cleaved at the carbon atom bond containing the carboxyl group by the action of Raney nickel.

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* See Consultants Bureau English translation, p. 2277.

PREPARATION AND SEVERAL PROPERTIES OF γ-FURYL-α-ALKYLALLYL ALCOHOLS

A. A. Arsenyuk

In one of the author's investigations [1] it was shown γ-furylallyl alcohol, obtained from furfurol by means of furylacrolein, polymerizes to form brittle tars, viscous thick oils, or masses with clearly expressed elastic properties. Upon the acetylation of γ-furylallyl alcohol with acetic anhydride in the presence of fused sodium acetate, the acetate, which is a pleasant smelling liquid, was obtained.

The present communication is concerned with experiments on the synthesis of several γ-furyl-α-alkylallyl alcohols and their acetates. The large amount of available literature material on the derivatives of allyl alcohol showed that the most successfull method for the preparation of γ-furyl- α-alkylallyl alcohols would probably be that using organomagnesium compounds. This method will allow the preparation of unsaturated alcohols under mild conditions which is very important for the synthesis of γ-furyl-α-alkylallyl alcohols containing a double bond in the relatively unstable furane nucleus. Of the secondary unsaturated alcohols containing an allyl residue and a furane, only α-allylfurfuryl alcohol had been obtained by this method [2,3]. The synthesis of this compound was effected in one step i.e. by the direct action of a mixture of allyl bromide and furfurol on magnesium. As a result of this reaction, 78% of theory of a brown liquid product boiling at 90-100° at 15 mm was obtained; after four vacuum redistillations, a comparatively small amount of α-allylfurfuryl alcohol with b.p. 96-97° (21 mm) was obtained. There are no results on the synthesis of secondary γ-furyl-α-alkylallyl alcohols by means of organo-magnesium compounds from furfurylacrolien, but there is a large amount of material on the preparation of corresponding (containing a phenyl residue) derivatives of allylic alcohols from cinnamaldehyde [2,4,5].

The many different syntheses effected by means of organo-magnesium compounds, made it possible to establish certain rules which can be used to predict the course of the reaction. For the preparation of secondary alcohols from aldehydes, it is necessary to conduct the synthesis in ether at low temperatures, and to use an excess of the alkyl magnesium halide [5]. In addition, the manner of decomposition of the reaction product of the alkyl magnesium halide with the carbonyl compound is always important. This operation is of unusually great importance for the synthesis of γ-furyl-α-alkylallyl alcohols because the latter, by the action of acidic agents (especially sulfuric acid), can dehydrate, isomerize, and tar [6,7 and others]. A series of experiments showed that the above secondary alcohols are obtained in good yield by the decomposition of the reaction products with ice, followed by the addition of a solution of ammonium chloride.

The following γ-furyl-α-alkylallyl alcohols (Table 1) were obtained from furylacrolein and the corresponding alkyl halide by means of the organo-magnesium synthesis.

The γ-furyl-α-alkylallyl alcohols synthesized, after vacuum redistillation, were pale yellow, oil-like liquids (resembling glycerol in their consistancy), with a characteristic odor. At ordinary temperatures, they are readily soluble in benzene, acetone, and ether, somewhat less – in alcohol, and practically insoluble in water.

On storage, especially in poorly closed vessels, the yellow color of the alcohol increases slowly, and then becomes red; after an extended period of time, they are transformed into transparent, wine-red, thick, (viscous) products.

The corresponding acetates (Table 2) were obtained by the acetylation of the γ-furyl-α-alkylallyl alcohols with acetyl chloride in the presence of pyridine.

The latter, in freshly prepared state, have a slight yellow color, possess an individual (rather pleasant) odor, and are more fluid than the alcohols. With the passage of time, the color of the esters slowly intensifies and then becomes red; according to their consistency, they become less fluid.

EXPERIMENTAL

I. Synthesis of γ-furyl-α-alkylallyl alcohols

1. Preparation of γ-furyl-α-methylallyl alcohol. 24.4 g (0.2 mole) of furylacrolein dissolved in 125-150 ml of ether was added stepwise from a dropping funnel, while the reaction flask was cooled with a mixture of ice and water, to a solution of methyl magnesium iodide prepared from 5.84 g (0.24 mole) of magnesium and 35.60 g

(0.25 mole) of methyl iodide in 75 ml of dry ether. Upon the addition of each drop of the furylacrolein, the formation of a yellow precipitate occurred, which, upon mixing the reaction mixture, dissappeared. The ether solution of furylacrolein must be added very slowly dropwise to the methyl magnesium iodide, because on conducting the reaction more rapidly, a considerable increase in temperature occurs resulting in a decrease of the yield of the alcohol synthesized. In order to attain a more complete reaction, the mixture was heated on the water bath to weak reflux of the ether for 2 hours. The product of the reaction of methyl magnesium iodide and furylacrolein was first cooled below zero degrees and then decomposed by the stepwise addition of ice to the flask, to which a cooled 25% ammonium chloride solution was then added. The ether solution of the alcohol was separated from the water layer; the latter was extracted 2 times with 50-25 ml of ether. The solution of the alcohol and the ether extracts were combined and dried with fused potassium carbonate. The residue, after the removal of the ether, distilled at 117.5-118.5° at 20 mm. An insignificant amount of tar-like products remained in the distillation flask. The yield of the γ-furyl-α-methylallyl alcohol in several experiments varied from 75.2-79.5%.

TABLE 1

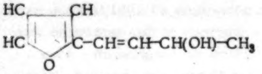
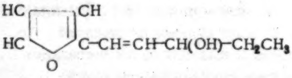
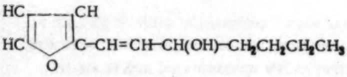
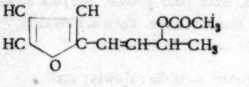
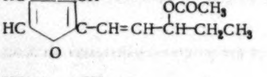
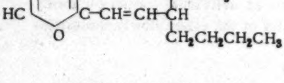
Alcohols	Boiling points at 20 mm	d_4^{20}	n_D^{20}	MR_D Found	MR_D Calc.	Exaltation
	117.5-118.5°	1.0573	1.5338	40.53	38.71	1.82
	128.0-128.5	1.0356	1.5300	45.31	43.33	1.98
	149.0-151.0	0.9967	1.5152	54.45	52.57	1.88

TABLE 2

Acetate	Boiling points at 20 mm	d_4^{20}	n_D^{20}	MR_D Found	MR_D Calculated	Exaltation
	126.0-127.0°	1.0607	1.5050	50.30	48.08	2.22
	132.0-134.0	1.0412	1.5028	55.02	52.69	2.33
	154.0-156.0	1.0067	1.4958	64.35	61.93	2.42

The freshly distilled alcohol was an oil-like, light-yellow liquid with an individual odor.

0.1007 g substance: 0.2610 g CO_2; 0.0687 g H_2O. Found %: C 69.13. $C_8H_{10}O_2$. Calculated %: C 69.56; H 7.30.

Upon the dehydration of γ-furyl-α-methylallyl alcohol with phosphorus pentoxide or iodine, a brittle, wine-red tar, transparent in thin layers, was obtained.

2. Preparation of γ-furyl-α-ethylallyl alcohol. 7.3 g (0.3 mole) of fine magnesium shavings, 32.7 g (0.3 mole) of ethyl bromide, and 24.4 g (0.2 mole) of furylacrolein were used for the synthesis. The same conditions

were used for the reaction as for the preparation of γ-furyl-α-methyl alcohol.

B.p. 128.0-128.5° at 20 mm. Yield 72.10% γ-furyl-α-ethylallyl alcohol was a light-yellow, oil-like liquid.

0.1478 g substance : 0.3862 g CO_2; 0.1048 g H_2O. Found %: C 71.29; H 7.93. $C_9H_{12}O_2$. Calculated %: C 71.03; H 7.95.

3. Preparation of γ-furyl-α-n-butylallyl alcohol. The alcohol was obtained from 7.3 g (0.3 mole) of magnesium, 27.8 g (0.3 mole) of normal butyl chloride, and 24.4 g (0.2 mole) of furylacrolein using the above conditions for conducting the reaction.

B.p. 149.0-150.0° at 20 mm. Yield 73.10%. Light yellow, glycerol-like liquid.

0.1341 g substance: 0.3596 g CO_2; 0.1046 g H_2O. Found %: C 73.16; H 8.73. $C_{11}H_{16}O_2$. Calculated %: C 73.33; H 8.95.

II. Synthesis of acetates of γ-furyl-α-alkylallyl alcohols.

1. Preparation of γ-furyl-α-methylallyl acetate. 13.8 g (0.1 mole) of the alcohol, 15.8 g (0.2 mole) of dry pyridine, and 10 ml of dry benzene were placed in a small, wide necked flask. The flask was closed with a stopper which contained a thermometer, calcium chloride tube, and a dropping funnel with a calcium chloride tube. The mixture of products was cooled below zero and then 11.8 g (0.15 mole) acetyl chloride was added to it dropwise with continuous stirring from the dropping funnel. The latter was added at such a rate as to keep the temperature of the reaction mixture from rising above +10°. After the addition of all the acetyl chloride, the reaction flask was left in the cooling mixture with intermittent mixing of the contents for 1 hour more. In order to attain a more complete esterification reaction, the mixture was allowed to stand at room temperature for half a day. The precipitated pyridine hydrochloride was dissolved in the minimum amount of water. The benzene layer of the acetate was separated from the water layer, washed with a dilute sodium bicarbonate solution, then with water, and dried with sodium sulfate. The benzene was removed on the water bath using a slight vacuum. γ-Furyl-α-methylallyl acetate vacuum distilled (20 mm) at 126.0-127.0°. Yield 69.10-75.5%. Oil-like (more fluid than the alcohol) light liquid. On storage, the yellow color of the ester intensified gradually and then became dark red.

The analysis of the ester was effected by saponification with titrated alcoholic sodium hydroxide solution. The saponification occurred upon weakly refluxing the alcohol for 2 hours. A blank experiment was made at the same time. 0.9768 g substance: 27.0 ml NaOH (T 0.008002). Found %: CH_3CO 23.75. $C_8H_9O_2(COCH_3)$ Calculated %: CH_3CO 23.89.

When the alcohol was acetylated with acetic anhydride under the same conditions, γ-furyl-α-methylallyl acetate with the above constants was obtained. Yield 55.3-60.4%.

2. Preparation of γ-furyl-α-ethylallyl acetate. 7.6 g (0.05 mole), 7.9 g (0.1 mole) of dry pyridine, 5 ml of dry benzene, and 5.9 g (0.075 mole) of acetyl chloride were used for the synthesis of the ester. The reaction was conducted under the same conditions as for the preparation of γ-furyl-α-methylallyl acetate. B.p. 132.0-134.0° (20 mm). Yield 82.0%.

0.9116 g substance: 23.48 ml NaOH (T 0.008002). Found %: CH_3CO 22.17. $C_9H_{11}O_2(COCH_3)$. Calculated %: CH_3CO 22.17.

3. Preparation of γ-furyl-α-n-butylallyl acetate. The ester was prepared from 9.0 g (0.05 mole) of the alcohol, and 5.90 g (0.075 mole) of acetyl chloride in a mixture of 7.9 g (0.1 mole) of pyridine and 5 ml benzene. The synthesis was effected as above. B.p. 154.0-156.0° (20 mm). Yield 81.50%.

0.8524 g substance: 19.15 ml NaOH (T 0.008002). Found %: CH_3CO 19.34. $C_{13}H_{15}O_2(COCH_3)$. Calculated %: CH_3CO 19.36.

SUMMARY

1. γ-Furyl-α-methyl, γ-furyl-α-ethyl-, and γ-furyl-α-n-butylallyl alcohols were obtained from γ-furylacrolein by means of the organo-magnesium synthesis.

2. The acetates of the synthesized γ-furyl-α-alkylallyl alcohols were obtained by the action of acetyl chloride in pyridine.

3. It was shown that the γ-furyl-α-alkylallyl alcohols and their acetates on storage (especially in open vessels) are capable of gradually changing into thick, viscous products.

4. Brittle tar like products are formed upon the dehydration of the γ-furyl-α-alkylallyl alcohols with phosphorus pentoxide and with iodine.

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* See Consultants Bureau English Translation, p. 663.

ALKALOIDS OF THE PAPAVERACEAE FAMILY

XI. OXIDATION OF ISOTHEBAINE

V. V. Kiselev and R. A. Konovalova

In the previous communication on the structure of isothebaine [1], it was shown that the previously accepted proposal on the distribution of the substituents in isothebaine was not true. Contrary to the above, the paper of Schlittler and Muller [2] reports results which support the earlier accepted formula of isothebaine (I). These authors synthesized a trimethoxyphenanthrene with m.p. 78.5°, picrate m.p. 159°. They assigned the structure 3,4 ,5-trimethoxyphenanthrene to this substance. On determining the melting point of mixtures of synthetic trimethoxyphenanthrene and its picrate with that obtained after the decomposition of isothebaine, Schlittler and Muller did not find any depression; on the basis of this they came to the conclusion that the final product of the decomposition of isothebaine is 3,4,5-trimethoxyphenanthrene, and therefore, the previously proposed structure of isothebaine is true. However, according to older literature results, 3,4,5-trimethoxyphenanthrene melts at 90° [3], and its picrate at 166-167° [3,4]. Schlittler and Muller do not explain the difference between the melting point reported by them and that given in the previous paper. In view of the above, the authors do not agree with the conclusion of Schlittler and Muller relative to the structure of isothebaine.

In order to investigate further the question of the position of the substituent groups in isothebaine, the oxidation of isothebaine was effected with potassium permanganate in acetone. As result of this reaction, 3-methoxyphthalic acid was obtained. Therefore, there is only one methoxy group in the benzene ring (formula II), located in the ortho position to carbon atoms 11 and 12. Therefore, the hydroxyl and the second methoxy group must be present in benzene ring B, and formula (I) is excluded because it does not correspond to the properties of isothebaine. If Position 1 is rejected for the methoxy group in ring A as being improbable because substances with substituents in this position are not found in the aporphine series of alkaloids, only Position 4 remains for it.

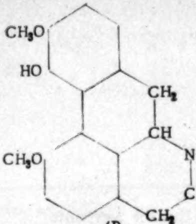
An attempt was made to try and confirm the distribution of the substituents of ring B by the oxidation of methylated isothebaine, thus to obtain dimethoxyhemimellitic acid from ring B, but again 3-methoxyphthalic acid and an acid of composition $C_{18}H_{16}O_9$, which apparently was trimethoxydiphenyltricarboxylic (III), were obtained.

Apparently the benzene ring B of methylated isothebaine is less stable to oxidation with permanganate than ring A. For comparison, an experiment was conducted on the oxidation of methylated corydine, in which the substituted hemimellitic acid once more could not be isolated. In place of the latter, an acid of the composition $C_{19}H_{18}O_{10}$ was obtained which must have the structure 5,6,5',6'-tetramethoxydiphenyl-2,3,3'-tricarboxylic acid (IV).

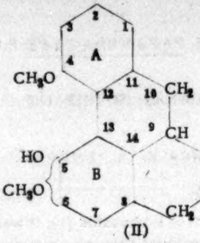
These results on the oxidation of methylated isothebaine and corydine agree with the results of a series of other investigations on the oxidation of aporphine alkaloids [5]. Therefore, evidently, a common property of the non-phenolic alkaloids of the aporphine series is the increase in the stability of ring A to oxidation by permanganate in comparison to Ring B.

EXPERIMENTAL

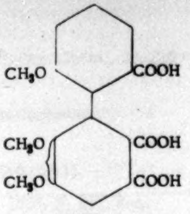
Oxidation of isothebaine. 3-Methoxyphthalic anhydride. 3 g of isothebaine was dissolved in 15 ml of 1 N H_2SO_4, the solution diluted with 80 ml of water, and the excess acid neutralized with 1 N NaOH. Then 21.9 g of potassium permanganate in 675 ml of water was added stepwise with stirring to the solution. At first the oxidation was conducted at room temperature, and after the decolorization slowed down, it was heated on the water bath to 50-60°. At this temperature, the addition of the oxidizing agent was continued until the color of the permanganate remained stable for 1 hour. The excess permanganate was decolorized by the addition of a small amount of sodium sulfite. The manganese dioxide was filtered and washed with hot water. The mother liquor, combined with the wash water, was acidified with strong hydrochloric acid, evaporated in vacuum to a volume of 25-30 ml, and extracted with ether. The ether extract, after drying over sodium sulfate, was evaporated. Weight of the residue, 1.91 g. From the residue, 0.68 g of a sublimate was obtained at 2 mm and 155-170°, which gave 0.31 g of a yellow crystalline substance with m.p. 156-157° upon recrystallization from 4 ml of toluene. After two recrystallizations from toluene, m.p. 159-160°. The substance is almost insoluble in cold water. Hot water rapidly dissolves it but on cooling crystallization does not occur; the reaction of the aqueous solution is acid to litmus and, weakly so, to Congo. Methyl and ethyl alcohols dissolve the substance with difficulty; upon boiling the solutions acquire an acidic reaction. The substance is difficultly soluble in benzene and toluene.



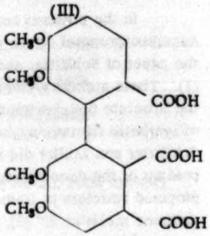
(I)



(II)



(III)



(IV)

The isolated anhydride did not give a depression in melting point upon mixing with 3-methoxyphthalic anhydride (m.p. 159.5-160°), obtained by the oxidation of 1,5-dimethoxynaphthalene. The melting point of the mixture, 159-160°. According to the literature, the melting point of 3-methoxyphthalic anhydride is 160-161° [6].

Aniline acid from 3-methoxyphthalic anhydride. 0.07 g of 3-methoxyphthalic anhydride was dissolved in 3 ml of hot toluene. A solution of 0.05 g of aniline in 0.5 ml of toluene was added to it. After some time, the whole solution was transformed into a continuous mass of fine, colorless crystals. 0.09 g was isolated. After recrystallization from 50% alcohol, 0.06 g of colorless platelets was obtained; upon slow heating, the m.p., 159-160°, upon rapid heating, the substance melted with frothing at 163°. After the solidification of the droplet, and heating once more, m.p. 187-189°. A sample of 3-methoxyphthalic acid and the mixture melted at 163° with frothing on rapid heating. Upon further heating, after the droplet solidified, the sample and the mixture melted at 187-190°. According to the literature, 3-methoxyphthalanilic acid melts at 164° with the formation of 3-methoxyphthalanil which has the m.p. 188.5-190° [6].

Oxidation of methylated isothebaine. 4.35 g of isothebaine methyl methosulfate was dissolved in water. A 3-4% solution of potassium permanganate containing 21.84 g of $KMnO_4$ was gradually added. The oxidation was conducted at 60-70° with stirring; when the oxidation slowed down, the temperature was raised to 80-85°, and the permanganate added until the color of the mixture remained stable for 1 hour. The excess permanganate was decolorized with sodium sulfite. The manganese dioxide was filtered and washed with hot water. The mother liquor and the water washings were evaporated in vacuum to a volume of 15-20 ml. The evaporated solution, after acidification with strong sulfuric acid, was extracted with ether. The ether extract, after drying over sodium sulfate, was evaporated. The residue was mixed with 20 ml of 20% potassium hydroxide. The solution was heated for one hour on the water bath, and then acidified and extracted with ether. After the evaporation of the ether extract, 2.1 g of a yellow tar was obtained, which was dissolved in 4.5 ml of water. Upon standing, 0.58 g of a slightly yellow crystalline acid separated from the solution. It melted at 240-241° upon slow heating; upon rapid heating, m.p. 175-180° with frothing, whereupon the substance crystallized immediately and melted once more at 240-241°. After recrystallization from water, the substance decolorized and melted without change. It is readily soluble in ethyl and methyl alcohol, slightly soluble in hot water, and very difficultly soluble in cold water and benzene. Aqueous solutions gave a weakly acidic reaction on Congo. Small amounts of the substance, initially heated to 210°, gave a green fluorescence in a dilute sodium bicarbonate solution, which disappeared upon standing. In a saturated solution of sodium bicarbonate, the fluorescence was barely noticeable and vanished rapidly; it vanished immediately upon the addition of acids or alkalies.

3.932 mg substance: 8.341 mg CO_2; 1.486 mg H_2O. 2.646 mg substance: 5.622 mg CO_2; 1.029 mg H_2O. 15,30 mg substance: 7.20 ml 0.1 N. $Na_2S_2O_3$. 18.75 mg substance: 8.88 ml 0.1 N. $Na_2S_2O_3$. Found %: C 57.85, 57.95; H 4.23, 4.35; OCH_3 24.33, 24.48. $C_{18}H_{16}O_9$. Calculated %: C 57.47; H 4.26; 3 OCH_3 24.73.

From the mother liquor, 0.10 g of the same, impure substance and 0.22 g of 3-methoxyphthalic anhydride were isolated.

Methylation of corydine. Corydine methyl ether methylmethosulfate. 4 g of corydine hydrochloride was mixed with 21 ml of 30% sodium hydroxide. 12.8 g of dimethyl sulfate was added to the mixture which was then slowly heated on the water bath, the saponification of dimethyl sulfate then became noticeable; when the reaction became somewhat violent, the flask had to be cooled with cold water. The mixture was transformed into a thick, white mass. The crystalline precipitate was filtered and washed with alcohol. After two recrystallizations from alcohol, 3.16 g of a substance with an m.p. of 247-248° was obtained. The crystals — shiny, white scales. Corydine methyl ether methylmethosulfate did not give a color reaction with ferric chloride; upon mixing aqueous solutions of the methylmethosulfate and potassium permanganate, a white precipitate formed.

Corydine methyl ether methiodide. Upon mixing an aqueous solution of the methylmethosulfate with an excess of a saturated solution of potassium iodide, the methiodide came out in the form of a finely crystalline precipitate. After two recrystallizations from alcohol, a methiodide with an m.p. 248-249° (with decomp.) was obtained.

Oxidation of methylated corydine. 5,6,5',6'-Tetramethoxydiphenyl-2,3,3'-tricarboxylic acid. 2.05 g of corydine methyl ether methylmethosulfate was dissolved in water. A solution of potassium permanganate was added to the solution under the same conditions as for the oxidation of methylated isothebaine. A total of 320 ml of an aqueous solution containing 11.52 g of potassium permanganate was consumed. The manganese dioxide was washed with hot water after filtration. The mother liquor and the water washes were combined and evaporated to a volume of 10-15 ml. After acidification with 3.5 ml of strong hydrochloric acid, a yellowish, crystalline precipitate formed which weighed 0.03 g. M.p. 195-200° with frothing. This substance was not investigated further. The acidic mother liquor was extracted with ether. 0.54 g of a colorless tar was obtained from the extracts. The tar was dissolved in 1.5 ml of water, and upon standing, 0.15 g of a substance crystallized which became fluid at 100°. After drying at 60-70°, the substance melted at about 125°, frothed, and at the same time, solidified. Upon further heating, the substance melted at 229-230.5°. If the substance was heated slowly, starting at 100°, it shrank at 120-125°, and at 229-230.5° it melted. After one recrystallization the melting point of the substance, well dried by slowly heating to 100°, was 230-231°.

15.25 mg substance: 8.7 ml 0.1 N $Na_2S_2O_3$. 11.70 mg substance: 6.7 ml 0.1 N $Na_2S_2O_3$. Found %: OCH_3 29.49, 29.61. $C_{19}H_{18}O_{10}$. Calculated %: 4 OCH_3 30.56.

SUMMARY

1. Upon the oxidation of isothebaine with permanganate, 3-methoxyphthalic acid was obtained. This showed the positions of the hydroxyl and methoxyl to be in the benzene ring of the tetrahydroisoquinoline nucleus of the aporphine skeleton. There is one methoxyl in the other benzene ring attached to position 1 or 4.

2. A common property of the non-phenolic alkaloids of the aporphine series was that the benzene ring of the tetrahydroisoquinoline nucleus was less stable, than the other benzene ring of the given aporphine derivative, to oxidation with permanganate in basic media.

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* See Consultants Bureau English Translation, p. 135.

[illegible] and vanillyl alcohol, [illegible]

0.882 mg substance: [illegible]
[illegible] mg substance: [illegible]
Found %: C [illegible]
[illegible]

From the mother liquor, [illegible] g of the [illegible] hydrate were isolated.

Methylation of coryd[illegible]. [illegible] was mixed with 21 ml of 20% sodium hydroxide [illegible] was then slowly heated on the water bath. [illegible] when the reaction became [illegible] transformed into a thick, white mass. [illegible] After two recrystallizations from alcohol [illegible] crystals [illegible] with ferric chloride, upon mixing [illegible] white precipitate formed.

Corydine methyl ether [illegible] to excess of a saturated solution of [illegible] line precipitate. After two recrystallizations [illegible] was obtained.

Oxidation of [illegible] of corydine methyl ether [illegible] was added to the solution under [illegible] of 200 ml of an aqueous solution containing [illegible] g of potassium permanganate [illegible] the solution was [illegible] and evaporated to a volume of [illegible] ed, crystalline precipitate formed [illegible] The [illegible] at 100° [illegible] same time, [illegible] ing point of the substance [illegible]

[illegible] mg substance: [illegible]
Found %: [illegible]

SUMMARY

1. Upon the oxidation of [illegible] with permanganate [illegible] the positions of the methoxyl and [illegible] of the [illegible] skeleton. [illegible]

2. A common property of [illegible] of the [illegible] tion of oxidation with permanganate to [illegible]

LITERATURE CITED

(1) [illegible]
[illegible]
[illegible]
[illegible]
[illegible]

Received April [illegible]

*See Consultants Bureau English Translation, p. [illegible]

ALKALOIDS FROM THE BRANCHY PLANTAIN

(PLANTAGO INDICA)

A. Danilova and P. Konovalova

The branchy plantain (Family Plantagenae) is an annual, grasslike plant prevalent in the Caucasus and the European part of the U.S.S.R. It was gathered by the Botanical Expedition of the All-Union Scientific Research Institut of Pharmaceutical Chemistry (VNIKhFI) under the leadership of P. C. Massagetov in July 1948, on sandy banks of the Khram River (Georgian S.S.R.).

The plantain has been known for a long time in folk medicine as a remedy for the healing of cuts and wounds, and for curing tuberculosis and dysentery. It is not surprising that this plant attracted the attention of various invetigators, who discovered glycosides, enzymes, organic acids, choline, and adenine in the plantain. However, there are no papers in the literature on the presence of alkaloids in the plantain.

The underground parts of the branchy plantain were investigated. Upon the extraction of the plant with dichloroethane in the usual manner, a mixture of alkaloids in 0.25% quantity based on the weight of the air dried plant was obtained. The separation of these alkaloids presented certain difficulties, and only after a great number of experiments could three individual alkaloids be isolated, which were new substances, unreported in the literature.

The first crystalline alkaloid was obtained in a small amount: it is proposed that it be called plantagonin. Its analysis suggests the formula $C_{10}H_{11}O_2N$. Plantagonin separates from an ether solution in the form of needles, gathered into clusters. After recrystallization from acetone, it melted at 218-220°; $[\alpha]_D + 30.8$ (1.1% HCl). It is poorly soluble in water and in organic solvents. It forms a picrate with m.p. 159-160°, a hydrochloride with m. p. 228-230°, °, and a chloroaurate with m.p. 151-152°. Plantagonin contains a hydroxyl group; neither a methoxyl group nor a methylimidyl group were detected.

The second alkaloid which was called indicamin, was a steam volatile liquid. Indicamin distills in vacuum at 75-92° (0.4 mm) in the form of a colorless liquid, discoloring slightly in the air, with a strongly expressed, basic odor. Its composition approximates the formula $C_{14}H_{23}ON$. It gives a picrate crystallizing from alcohol with m.p. 127-129°. Indicamin is an unsaturated base, and immediately decolorizes potassium permanganate in the cold.

The third alkaloid – indicain – has the composition $C_{10}H_{11}ON$. It is liquid base, volatile with steam. Indicain distills in vacuum at a somewhat higher temperature (b.p. 92-105). Its picrate melts at 151-153° after recrystallization from ethyl acetate.

A more detailed study of the alkaloids separated was not undertaken because of an insufficient quantity of the plant.

EXPERIMENTAL

1. Separation of total alkaloids. 14 kg of the dried, finely ground plant was moistened with 10% ammonia, and exhaustively extracted with dichloroethane. The alkaloids were extracted from the dichloroethane solution with 10% sulfuric acid The acid solution was filtered, cooled, and made alkaline with 25% ammonia. The alkaloids were extracted from the alkaline solution with ether at the start and then with chloroform.

2. Isolation of alkaloids from the ether solution. Upon standing, crystals gathered into clusters, separated from the ether solution of the alkaloid on the bottom and the sides of the flask. The crystalline substance was filtered, washed with acetone, and dried at 60°. The crystalline base, called plantagonin by the authors, weighed 1.22 g. After two recrystallizations from acetone (1:100), m.p. 218-220°, weight 0.6 g. A portion of the substance was recrystallized from 96% alcohol; the melting point did not change.

Plantagonin is poorly soluble in water and organic solvents, and completely insoluble in benzene. Upon heating it dissolved in water, chloroform, ethyl acetate, and alcohol. A sulfuric acid solution of plantagonin did not decolorize permanganate. Plantagonin is an optically active base.

0.2206 g substance: in 4 ml 1.1% HCl; α_D + 0.85; $[\alpha]_D$ + 30.8° where l = 0.5 dm.

4.190 mg substance: 10.466 mg CO_2; 2.32 mg H_2O. 6.03 mg substance: 0.412 ml N_2 (21.5°, 745 mm). Found %: C 68.12; H 6.19; N 7.76. $C_{10}H_{11}O_2N$. Calculated %: C 67.79; H 6.21; N 7.90.

Plantagonin hydrochloride. The base was dissolved in an alcoholic hydrogen chloride solution and precipitated with ether. The precipitated hydrochloride was filtered and washed with water. After two reprecipitations, the hydrochloride melted at 228-230° with decomposition.

2.698 mg substance: 1.778 mg AgCl. Found %: Cl 16.30. $C_{10}H_{11}O_2N \cdot HCl$. Calculated %: Cl 16.62.

Plantagonin picrate. 0.05 g of plantagonin was dissolved with heating in 3 ml of water; a saturated aqueous solution of picric acid was added to the cooled solution. A finely crystalline powder separated from the mixed solutions upon standing. This powder was filtered, washed with water, and dried at 60°. After two recrystallizations from water, m.p. 159-160°.

4.035 mg substance: 0.518 ml N_2 (22°, 732 mm). Found %: N 14.31. $C_{10}H_{11}O_2N \cdot C_6H_3O_7N_3$. Calculated %: N 13.79.

Plantagonin chloroaurate. 0.05 g of plantagonin was dissolved in 3 ml of 10% hydrochloric acid, and 0.3 ml of an aqueous $HAuCl_4$ solution was added to it. Oil-like droplets separated from the mixture, which dissolved upon heating on the water bath. Upon slowly cooling, needle-like crystals of the chloroaurate separated. After recrystallization from dilute hydrochloric acid, m.p. 151-152°.

4.782 mg substance: 1.812 mg Au. Found %: Au 37.89. $C_{10}H_{11}O_2N \cdot HAuCl_4$. Calculated %: Au 38.12.

Plantagonin formed a crystalline methiodide without a clear melting point, and which was very difficult to purify.

Isolation of the liquid alkaloids. The ether solution, after the removal of the crystalline alkaloid, was shaken several times with 10% sodium hydroxide, and then washed with water and dried over Na_2SO_4. After the removal of the ether, 27.8 g of liquid bases was obtained. The alkaloids obtained were steam distilled. The steam volatile bases distilled in the form of oily droplets immiscible with water. The distillate was extracted with ether. The ether solution was dried over Na_2SO_4. After the removal of the ether, 1.46 g of liquid alkaloids with a characteristic odor was obtained.

The residue in the flask after the removal of the volatile bases, consisted of two layers, a tarry layer and a clear aqueous layer. No pure alkaloids could be isolated from the tarry layer. A saturated aqueous solution of picric acid was added to the aqueous layer. A crystalline precipitate separated from the mixture upon standing. After two recrystallizations, first from alcohol and then from ethyl acetate, a picrate with m.p. 149-150° was obtained. From the mother liquor, a small amount of a picrate was isolated which melted at 124-127° after recrystallization from alcohol.

The liquid bases (1.46 g) were vacuum distilled (0.4 mm). Two fractions were collected: with b.p. 75-92° (0.57 g) and with b.p. 92-105° (0.5 g).

Indicamin. A picrate was obtained from the first fraction with an alcoholic picric acid solution, which melted at 127-129° after many recrystallizations from alcohol. The picrate is readily soluble in ethyl acetate, dioxane, acetone, and chloroform, and poorly soluble in water.

3.485 mg substance: 6.810 mg CO_2; 1.749 mg H_2O. 4.026, 4.148 mg substance: 0.428, 0.431 ml N_2 (20°, 16°, 744.5, 752.2, mm). Found %: C 53.29; H 5.61; N 12.15, 12.16. $C_{14}H_{23}ON \cdot C_6H_3O_7N_3$. Calculated %: C 53.57; H 5.36; N 12.47.

Indicain. A picrate with m.p. 145-146° was obtained from the second, higher boiling fraction with an aqueous solution of picric acid. After three recrystallizations from ethyl acetate, indicain picrate melted at 151-153°.

3.686 mg substance: 6.693 mg CO_2; 1.196 mg H_2O. 3.656 mg substance: 0.464 ml N_2 (18.0°, 727.5 mm). Found %: C 49.52; H 3.63; N 14.25. $C_{10}H_{11}ON \cdot C_6H_3O_7N_3$. Calculated %: C 49.23; H 3.58; N 14.35.

Isolation of alkaloids from the chloroform solutions. 6 g of tarry, non-crystalline bases was obtained from the chloroform solution. Upon attempting to purify them by means of salts, it was found that the picrate, the tartrate, and the hydrochloride tarred upon the slightest heating.

The analyses were made at the microanalytical laboratory of VNIKhFI, directed by V. V. Kolpakova.

SUMMARY

1. Three new alkaloids were isolated from the Caucasian branchy plantain: plantagonin, composition $C_{10}H_{11}O_2N$; indicamin, $C_{14}H_{23}ON$, and indicain, $C_{11}H_{11}ON$.

2. The Caucasian plantain is the first alkaloid-carrying representative of the family Plantagenae.

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DISCUSSION

ERRORS OF A.A.KALANDIYA IN HIS PAPER "COMPUTING THE MOLECULAR VOLUMES OF INORGANIC COMPOUNDS OF THE $A_nB_mO_s$ TYPE"[*] AND HIS ATTEMPTS TO SUPPORT THE ERRONEOUS RESONANCE CONCEPT

G.V.Tsitsishvili

The author of the paper cited, A.A.Kalandiya, proposed a formula for the calculation of molecular volumes of inorganic compounds of the $A_nB_mO_s$ type, and in conclusion wrote: " it should be stated that the theoretical considerations we have set forth here make it possible to compute the molecular volumes of compounds of the foregoing type accurately by means of the formula proposed by us."

Let us examine the basic steps of the "theoretical" discussion of A.A.Kalandiya, so that we may evaluate them and see whether or not A.A.Kalandiya was justified in making such an all-promising conclusion. For clearness, we will give an excerpt from the initial discussion of A.A.Kalandiya (see p. 1635 and 1636[**]): " To compute the molecular volumes of compounds of the foregoing type ($A_nB_mO_s$) we made use of the formula proposed by us to compute interatomic distances in compounds of this type.

"In brief, this is the solution of the latter problem. In accordance with Coulomb's law, the mutual attraction between the B^{z+} and O^{t}[***] ions should be:

$$\frac{z_2z_3e^2}{r^2}.$$

" Now let us consider the instant when the anion $B_mO_s^{y-}$ and the cation A_n^{x+} approach each other to the distance of the radius required for their mutual attraction and the O_s^{f-} and A_n^{x+} ions mutually attract each other. As O_s^{f-} constitutes the intermediate bridge transmitting the mutual attraction of the O_s^{f-} and A_n^{x+} ions, on the one hand, and the attraction of the O_s^{f-} and B_m^{z+} ions on the other, the latter depends not only on the distance between them but also on the number of ions in the molecules and on the magnitude of their charges. For instance, in $NaClO_4$, the Cl – O distance equals 1.59 A; this distance is likewise 1.59 A in $KClO_4$; in Ag_3PO_4 the P – O distance is 1.61 ± 0.03 A; in BPO_4 this distance is 1.54 A, etc. Hence, the force of mutual attraction, F_1, between the ions of the anion $B_mO_s^{y-}$ when acted upon by the cation A_n^{x+}, from the empirical data cited above, must equal:

$$F_1 = \frac{Az_1z_2z_3z_4e^2}{r_1^2} \qquad (1)$$

"Owing to the fact that their charges are of like sign, the A_n^{x+} and B_m^{z+} ions repel each other, the force of mutual repulsion, F_2, equalling:

$$F_2 = \frac{Az_1z_2e^2}{r_2^2} \qquad (2)$$

"From Equations (1) and (2) it is apparent that the repulsive forces will be positive, and the attractive forces negative, as the former will exist for like signs on z_1 and z_2, and the latter exist for unlike charges. Hence, summing up, we find that the aggregate attractive force F must be:

$$F = F_1 + F_2 = -\frac{Az_1z_2z_3z_4e^2}{r_1^2} + \frac{Az_1z_2e^2}{r_2^2}, \qquad (3)$$

where F = attractive force of the foregoing ions; A = Madelung's constant, depending chiefly upon the number of ions in the molecule; $\underline{e}$ = the charge on an electron; z_1 = the amount of charge employed for the bond with element $\underline{A}$; z_2 = the amount of charge employed for the bond with element $\underline{B}$; z_3 = the amount of charge employed for the bond with element $\underline{O}$; z_4 = the amount of charge employed for the bond between element O and one element of the cation; r_1 = the distance between the B_m^{z+} and O_s^{f-} ions, i.e., $R_{z_2z_3}$; r_2 = the cation radius, R_{z_1}.

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[*] See Consultants Bureau English Translation, p. a-59 ff.

[**] See Consultants Bureau English Translation, p. a-59-a-61.

[***] Here, obviously, it must be O_s^{f}.

$$R_{z_1} + R_{z_2z_3} = R_{z_1z_2z_3}\text{ ."}$$

The style of Kalandiya will not be discussed here, only the essentials of the question. There is practically no basis for the expression for the attractive forces (see Equation 1). The introduction of the constant coefficient $\underline{A}$, which Kalandiya glorifies as the 'Madelung Constant', has no basis here at all. The constant coefficient in the energy of attraction is a function of the type of lattice in the solid; it is usually used for the electrostatic calculation of the lattice energy. Here Kalandiya attempts to calculate the reaction between $\underline{m}$ positive ions B and $\underline{s}$ negative ions O. It is nowhere shown that the attractive force, F_1, is actually proportional to z_3 and z_4. It is appropriate to point out that in the foregoing foggy text, it is almost impossible to comprehend the significance of z_1, z_2, z_3, and z_4. For instance, Kalandiya writes that: "z_1 = the charge employed for the bond with element A." One must ask — the value of what charge and, probably, employed, rather than occupied by, as the author writes:)[*] for the bonds of what ions (and not elements, as the author confuses it)?

The force of mutual attraction, F_1, according to Equation (1) is inversely proportional to r_1^2, with Kalandiya stating that r_1 = the distance between B_m^{z+} and O_s^{f-}. It is obviously necessary to take into consideration the chemical structure when characterizing the distance between the complex cation and complex anion. Kalandiya did not trouble to do this, and characterized the distance between complex ions in the same manner as for simple ions.

Equation (2) for the force of repulsion is also baseless. How can the force of rupulsion between the ions A_n^{x+} and B_m^{z+} be inversely proportional to the square of the radius of the cation. It is impossible to understand how the first member of the right side of Equation (3) obtained its minus sign, since, according to Equation (1), $F_1 = \dfrac{Az_1z_2z_3z_4e^2}{r_1^2}$. Why does Equation (3), which should, evidently, express the aggregate attraction force, not take account of the reaction between the ions A_n^{x+} and O_s^{f-} ?

The author continues:

"The energy of formation of the anion U_1, arising as the result of the approaching of the ions (from infinity to the distance $R_{z_2z_3}$), will be:

$$\overset{\infty}{U_1} = -\int_{\infty}^{R_{z_2z_3}} F_1dr_1 = \int_{\infty}^{R_{z_2z_3}} \frac{z_1z_2z_3z_4e^2}{r_1^2}\,dr_1 = -\frac{z_1z_2z_3z_4e^2}{R_{z_2z_3}}.$$

"At the instant the ions with complete electron shells come into contact or approach each other, the force of repulsion, approximately equal to B/R^n, is generated; hence, the complete energy of interaction between the ions is:

$$U_1 = -\frac{Az_1z_2z_3z_4e^2}{R_{z_2z_3}^2} + \frac{B}{R_{z_2z_3}^n}\,. \tag{4}$$

"Upon differentiation of this equation we get:

$$\frac{dU_1}{dR} = \frac{Az_1z_2z_3z_4e^2}{R_{z_2z_3}^2} - \frac{nB}{R_{z_2z_3}^{n+1}} \gg\text{."}$$

"

Kalandiya subsequently writes:

$$\text{"}R_{z_2z_3} = \sqrt[n-1]{\frac{nB}{Az_1z_2z_3z_4e^2}}\,. \tag{5}$$

"Assuming that we are dealing with univalent elements, we find from Equation (5) that:

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[*] The Russian word originally used by Kalandiya has various synonyms, and might be translated as: occupied by, busied with, employed for. In the translation of the Kalandiya paper discussed here, Consultants Bureau chose the latter translation as most probably conveying the author's meaning.

$$R_{11(z_2z_3)} = \sqrt[n-1]{\frac{nB}{Ae^2}} \quad . \text{"} \tag{6}$$

Kalandiya mechanically dissects the energy of interaction from the energy of attraction and repulsion. As a result of this, the repulsion force mysteriously arises for Kalandiya at the instant of the mutual approach of the ions.

Here Kalandiya also quite incomprehensibly takes the attraction force as equal to $-\frac{Az_1z_2z_3z_4e^2}{r_1^2}$, and not as he gives in the first formula.

Kalandiya expresses the repulsion force by means of the formula $\frac{B}{R^n}$ and, disregarding elementary rules on the addition of like dimensions, adds the repulsion force to the energy of attraction [see p. 1637, Equation (4)]*.

Kalandiya, on the basis of such self-formed "theoretical" material, where he uses, as he says "empirical" results, proposes a formula for the distance between the ions B_m^{z+} and O_s^{f-} [see p. 1637 equation (7)]: *

$$R_{z_2z_3} = \frac{R_{11(z_2z_3)}}{\sqrt[n-1]{z_1z_2z_3z_4}} \tag{7}$$

Further Kalandiya writes:

"If we compute F_2 analogously from Equation (2), we get:

$$R_{z_1} = \frac{R_{1(z_1)}}{\sqrt[n-1]{z_1z_2}} . \tag{8}$$

"As was stated above, $R_{z_1} + R_{z_2z_3} = R_{z_1z_2z_3}$; hence, it follows from Equations (7) and (8) that:

$$R_{z_1z_2z_3} = \frac{R_{11(z_2z_3)}}{\sqrt[n-1]{z_1z_2z_3z_4}} + \frac{R_{1(z_1)}}{\sqrt[n-1]{z_1z_2}} ,$$

i.e.,

$$R_{z_1z_2z_3} = \frac{R_{11(z_2z_3)} + \sqrt[n-1]{z_3z_4R_{1(z_1)}}}{\sqrt[n-1]{z_1z_2z_3z_4}} . \tag{9}$$

"We introduce the coefficient K of the coordination number to be expressed, and get:

$$R_{z_1z_2z_3} = K \cdot \left(\frac{R_{11(z_2z_3)} + \sqrt[n-1]{z_3z_4 R_{1(z_1)}}}{\sqrt[n-1]{z_1z_2z_3z_4}} \right) \cdot \tag{10}$$

etc.".

Kalandiya, from the beginning of the above quotation, apparently set himself the goal of calculating F_2, but in reality, quotes the value of R_{z_1}. Of what accurate analogy does the author speak for the calculation of F_2 — it is uncertain. If the calculation of F_2 is effected as accurately as the calculation of F_1, then such accuracy cannot be imagined. How the value R_{z_1} was obtained is unknown. The author evades this by silence. It is completely impossible to reconcile equations (9) and (10), where there are identical left parts of the equation and different right parts. Here the author again exceeds the limits of common mathematical rules, and uses his own mathematics. The suggestion "Introducing the coefficient K of the coordination number to be expressed" has no basis, and is not related to the preceeding text. As for equations (5) and (7) on page 1637, Kalandiya here attempts to account for the influence of foreign ions on the distance between the ions B_m^{z+} and O_s^{f-}. Assuming that the ions are monovalent, he obtains for $R_{11(z_2z_3)}$ the well-known expression for the radius of a monovalent ion. Therefore, it is clear that if the foreign ions possess a single charge, they have no influence. The effect of the foreign ions on the above distance must, evidently, decrease as a function of the decrease in the charges, in other words, $R_{z_2z_3}$ must approach $R_{11(z_2z_3)}$ when the charge on the foreign ion approaches zero. What have we in reality? It is not difficult to see that, when the denominator approaches zero, the expression for $R_{z_2z_3}$ approaches infinity. The result, as in the previous case, is obviously absurd.

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* See p. 1639. (p. a-61 and a-62 in English translation).

Kalandiya continues with a foggy discussion on the coefficient of repulsion and proposes some sort of "mixed" calculation, which he does not explain further. We quote again from Kalandiya's paper: "As we are of the same opinion: that the effective radius of atoms or ions is the starting point for computing molecular volume, computing the magnitude of molecular volume of compounds of the type mentioned requires the interatomic distance derived from Equation (10), proposed by us for determining the interatomic distance between the centers of the anion and cation, multiplied by the coefficient A and by 10^{-8} [for compounds of the $A_2(BO_4)_3$ type, coefficient A is 1.5, and equals unity for all the other compounds investigated by us]. The result is then cubed and multiplied by PN, i.e., by the number of atoms or ions (P) that make up the molecule, and by Avogadro's number (N), after which it is divided by the sum of the ratio of the interatomic distance of the compound considered to the interatomic distance of the anion plus the coefficient of repulsion, $\underline{n}$ (= 9), multiplied by the constant $\underline{1}$ (= 0.1).

"Thus, the formula proposed by us for computing the molecular volume finally takes on the following form:

$$V = \frac{\left[\left(\dfrac{R_{11(z_2z_3)} + \sqrt[n-1]{z_3z_4}\cdot R_{1(z_1)}}{\sqrt[n-1]{z_1z_2z_3z_4}}\right) K A\, 10^{-8}\right]^3 PN}{\underline{1}\cdot\left\{n + \left[\left(\dfrac{R_{11(z_2z_3)} + \sqrt[n-1]{z_3z_4}\cdot R_{1(z_1)}}{\sqrt[n-1]{z_1z_2z_3z_4}}\right) K A\, 10^{-8} : \dfrac{R_{1(z_2z_3)}}{\sqrt[n-1]{z_1z_m}}\cdot 10^{-8}\right]\right\}},$$

where z_m = the aggregate sum of the charges employed for bonds with the ions (or atoms) that are interconnected with the central ion. Thus, for instance, anions of the XO_3^{y-} type, the aggregate sum of the charges employed by the O^{--} ion for bonds to the central ion (or atom) as well as to the cation equals 6, while it equals 8 for anions of the XO_4^{y-} type, 8 for anions of the $X_2O_4^{y-}$ type, 14 for anions of the $X_2O_7^{y-}$ type, and this sum is taken by us as equal to unity for $(CN)^-$ and $(NH_4)^+$, respectively."

From this text it is seen that Kalandiya proposes a formula for the calculation of molecular volume, but in no way bases it on physical considerations. Here she uses a series of arbitrary coefficients and formulas, for molecular volume, given always in complicated form. Kalandiya tried to give an impression of solidity to the formulas for molecular volume, without consideration for either chemical or physical bases. There is an algebraic absurdity in the formula itself, which it is pointless to discuss here.

For the application of the above formula, Kalandiya calculates molecular volumes. We quote the text of Kalandiya concerned with the calculation, and then we will return to the calculation itself: "Solving an example by means of the formula proposed by us for computing molecular volume is done as follows. Let us take as an example $NaIO_4$, for which $\underline{n}$ averages 7; $R_{11(z_2z_3)} = 0.77$ A + 1.76 A; $R_{1(z_1)} = 0.98$ A; $z_1 = 1$; $z_2 = 7$; $z_3 = 2$; $z_4 = 1$; and $z_m = 8$; the coefficient K, expressing the coordination number, equals 1.044; the number of atoms entering into the composition of the molecule is 6; and coefficient A = 1. Hence,

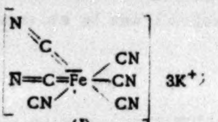
$$V = \frac{\left[\left(\dfrac{0.77 + 1.76 + \sqrt[6]{2\cdot 1}\cdot 0.98}{\sqrt[6]{1\cdot 7\cdot 2\cdot 1}}\right)\cdot 1.044\cdot 10^{-8}\right]^3\cdot 6\cdot 6.06\cdot 10^{23}}{0.1\left\{9 + \left[\left(\dfrac{0.77 + 1.76 + \sqrt[6]{2\cdot 1\cdot 0.98}}{\sqrt[6]{1\cdot 7\cdot 2\cdot 1}}\right)\cdot 1.044\cdot 10^{-8} : \dfrac{0.77 + 1.76}{\sqrt[6]{1\cdot 8}}\cdot 10^{-8}\right]\right\}} = 51.0 \text{ ml.}$$

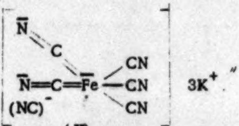
"The answer should have been 51.1 ml. Hence, the error is 0.1 ml, i.e., the agreement is extremely good.". It is strange that the meaning of the value K is not clarified in the text. K, according to Kalandiya, "is the coefficient of the coordination number to be expressed" (see the first line of p. 1639). In the text K is also used to designate the coordination number, the author stating that she used the values given by Zachariasen. Which does K represent – the coordination number or a function of it? It is generally difficult to discuss a puzzle of this sort. It is impossible to understand why Kalandiya used K = 1.044 for $NaIO_4$. Almost nothing is given as the basis of the value of the coefficient A, which Kalandiya takes to equal unity in the case of $NaIO_4$.

In the formula for molecular volume (why is this formula without a number ?), Kalandiya states that he takes the repulsion coefficient as 9. When he returns to the calculation of the $NaIO_4$ example, she assumes that it "averages 7" Here Kalandiya once more withdraws into his usual terminological fog. What is meant by the "average" repulsion coefficient, and, strictly speaking, on the basis of what data does Kalandiya take it to be 7 for $NaIO_4$, 7.3 for $NaBrO_3$, and 8.3 for $CoWoO_4$ and 9.3 for $PbMoO_4$ (see p. 1641, Table 3)*, etc. Surprisingly, when he turns to the calculation itself, which according to the above-cited statements must employ the value of $\underline{n} = 7$ for the case of $NaIO_4$, this value now becomes 9 and not 7. If $\underline{n}$ is taken as equal to 7 (in accordance with the text and Table 3), the value obtained for the molecular volume, V, is not 51.5 ml. V, for $\underline{n} = 7$, is about 63, not milliliters, but $63 \cdot 10^{24}$ ml. After all these operations, Kalandiya "obtains" the value 51.0 for the molecular volume of $NaIO_4$** which he states is close to the experimental value for the molecular volume. On the basis of what data the molecular volume value was obtained is not cited, of course "for clarity". Apparently, this calculation, the secret of whose operation is known only to Kalandiya, is scarcely of any use.

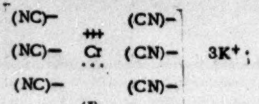
Kalandiya, undaunted, proposed to apply his formula further, for calculation of the molecular volume to complex compounds. Here Kalandiya states:

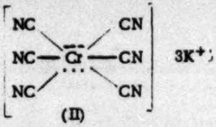
"Let us take, for example, $K_3Fe(CN)_6$, the structure of which is represented, according to Ya. K. Syrkin and M.E.Dyatkina**, by one of the following two variants:

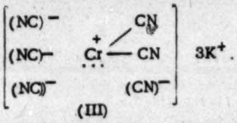

(I)


(II)

Kalandiya calculated the molecular volume for both "variants" (Kalandiya expression) of potassium ferrocyanide, and came to the specific conclusion that " in the foregoing compound, the structure is better expressed as the first variant" (see page 1643)***. The author further analyzes, from the same position, the coordination compounds, in particular $K_3Cr(CN)_6$. Here he writes: " Even more interesting are the results obtained for $K_3Cr(CN)_6$. Its structure may be represented by any one of the following thre variants:


(I)


(II)


(III)

"According to Ya.K.Syrkin and M.E.Dyatkina, the existence of structures such as those expressed by the first and second variants is allowable under the concept of their being mutually superposed on one another." Kalandiya once more, in his own way, calculates the molecular volume, and finally comes to the conclusion: "It must be assumed that the structure assigned to $K_3Cr(CN)_6$ by Ya.K.Syrkin and M.E.Dyatkina in the second variant predominates over all the other structures expressed by the other variants in the state of mutual superposition of one over another."

It is not difficult for the reader to see that all of the foregoing arguments of Kalandiya result in the anti-Butlerov representation of multi-structureness of molecules, and in a defence of the highly erroneous and methodologically defective, idealist concept of resonance. Kalandiya uses his "theoretical considerations" on molecular volumes to demonstrate that non-existent, fictious structures exist and possess the properties of compounds.

It is easy to see from the text that Kalandiya did not find time to study the literature on the question of molecular volume. He indicates that its history began with Bilts. Kalandiya would have found very enlightening the Journal of the Russian Physico-Chemical Society", as well as the wealth of Soviet chemical literature and other native sources. Kalandiya completely fails to relate the properties of a compound to its chemical structure. He has not taken into consideration Butlerov's theory of chemical structure. Kalandiya, in his paper which contains elementary and obvious physical and mathematical errors, is a defender of the scientifically insolvent and methodologically defective, idealistic concept of resonance.

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[*] See Consultants Bureau English Translation, p. a-66.

[**] In the Journal, there is an obvious typographical error, as the molecular volume is given as 5.10 ml. (This misprint was not repeated in the English translation. Publisher.)

[***] The Chemical Bond and the Structure of Molecules, Syrkin and Dyatkina, State Chemical Press.

[illegible]

[illegible] Kalmykova [illegible]

Kalmykova [illegible]

[illegible] for example, [illegible]

Kalmykova [illegible]

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